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Sourcing Monterey banded chert, a cryptocrystalline hydrosilicate : with emphasis on its physical and thermal traits as applied to central California archaeology

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SOURCING MONTEREY BANDED CHERT, A CRYPTOCRYSTALLINE HYDROSILICATE: With Emphasis on Its Physical and Thermal Traits as Applied to Central California Archaeology

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The Faculty of the School of Social Science

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In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

By

Gary Alan Parsons

May, 1990

APPROVED FOR THE DEPARTMENT OF SOCIAL SCIENCE

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Dr. Wayne Savage, Ph.D.

Dr. William R. Hildebrandt, Ph.D.

APPROVED FOR THE UNIVERSITY

SOURCING MONTEREY BANDED CHERT, A CRYPTOCRYSTALLINE HYDROSILICATE: With Emphasis on Its Physical and Thermal Traits as Applied to Central California Archaeology

by Gary Alan Parsons

Abstract

This research project began by observing coastal Monterey Banded (MB) Chert within many inland archaeological sites of Central California. Archaeologists are concerned with the origin of materials they unearth and could only speculate on the origin of many lithic materials. However, MB Chert contains petroleum, and laboratory procedures exist for fingerprinting petroleum fractions. This project fingerprinted geologic occurrences and sourced artifacts manufactured from MB Chert, back to their geological point-of-origin. Prehistoric inhabitants of Central California heat-treated siliceous materials to improve workability. This project established that thermal alteration had no adverse effects on the fingerprinting process. A review of 789 lithic collections from Central California revealed 366 sites containing MB Chert. Intersite variability appeared dependent on location and proximity to other lithic sources. Distribution of MB Chert inland from coastal sources persisted through the Central California Coast Range and well into the San Francisco Bay Area. However, tapered-off drastically through the Diablo Range and stopped abruptly at the San Joaquine Valley.

Dedication

This research thesis is dedicated to my wife, Patricia, and my four children (Scott, Cristin, Melissa, and Kathleen) for their patience and understanding during the time I spent away from home, taking classes, field work, and my absence during the preparation of this thesis.

Acknowledgments

I would like to thank the following people for their valuable assistance in obtaining lithic materials from archaeological sites throughout Central California:

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- Roger Werts, Chuck Scimeca, and Nina Gordon from the California State Department of Parks and Recreation in San Mateo County; and
- The many private collectors for making their artifacts of MB Chert available for this study.

I would also like to thank the many land owners (both government and private) for allowing myself and the field school from San Jose State University access onto their property. The following families are: Bradley, Brown, Henky, Hoover, Leynse, McCrary, Muzze, Pope, Steele, and Wells; the many government agencies for their assistance in obtaining all of the required permits and waivers; and also, the Native American (Ohlone) community for their assistance in all matters. The primary families were: Mrs. Dolores F. Franco of San Jose, Mrs. Margeret Martinez of San Jose, Mrs. Ella Mae Rodriguez of Salinas, and especially Mrs. Rosemary Cambra and her family, who are direct descendants of the Alisal Rancheria near Pleasanton, California.

A special thanks goes to Dr. Wayne Savage of San Jose State University for his help and guidance during the structural and thermal phases of this research project. Dr. Savage graciously made the scanning electron microscopy facilities of the Biological Sciences Department available to the exhaustive demands of this study, day and night. A special thanks also goes to the technicians from SRI International in Menlo Park, California (Eldon Farley, Robert Gates, Bob Brittain, Gill St. John, and Jan Terry) for all their help and cooperation in the many analytical tests needed for this research project. Also, my thanks to Jan Witlow for generously editing and Gary Breschini for proofreading this research manuscript.

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Signature Gary A. Parsons Date May 26, 1990

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CHAPTER I: INTRODUCTION

Introduction

Establishing the precise origins of various artifactual materials is an important task of the archaeologist. The origin of artifacts is needed for studying the social and economic interaction between prehistoric cultures (who traded what, with whom, and when). Within the past few years, sourcing artifacts through sophisticated analytical techniques has become an accepted procedure. The most widely used lithic sourcing technique used in archaeology is x-ray fluorescence (XRF), used to source obsidian. However, sourcing of hydrosilicates, such as chert, has not been successful until recently. Employing field ionization mass spectrometry (FIMS) has made it possible to reliably fingerprint Monterey Banded (MB) Chert and thus, has made it practical to source MB Chert back to its geologic point of origin.

The FIMS analyzes hydrocarbon components within organic compounds and lithic materials. This process ionizes a specimen's volatile organic components and records the results in both numeric (Figure 1) and histogram form (Figure 2). A large portion of the hydrocarbon content within MB Chert contains crude petroleum, trapped within the chert's porous structure. When freshly broken or overheated, MB Chert releases a pungent odor of crude petroleum. Before being altered by naturally occurring

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G.PARSONS, A-3  1- 8                                          N AV MW: 351.3
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MAG. RET. TIME: 9999 MS,   8 SCANS/SPECTRM.        49 TO  449 DEG. C   SF= 1
INTENSITIES NORMALIZED TO 100000.                                      PG. 1
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EV     8597.8     9245.2     9454.8    10421.6           10043.9     8566.6     8445.8
RATIO    0.53591    0.56857    0.58529    0.49480            0.49429    0.54918    0.59207
OVERALL RATIO OF ODD TO EVEN MASS PEAKS    0.543789
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Figure 1. Numeric results obtained from the FIMS analysis of a sedimentary rock's hydrocarbon content.

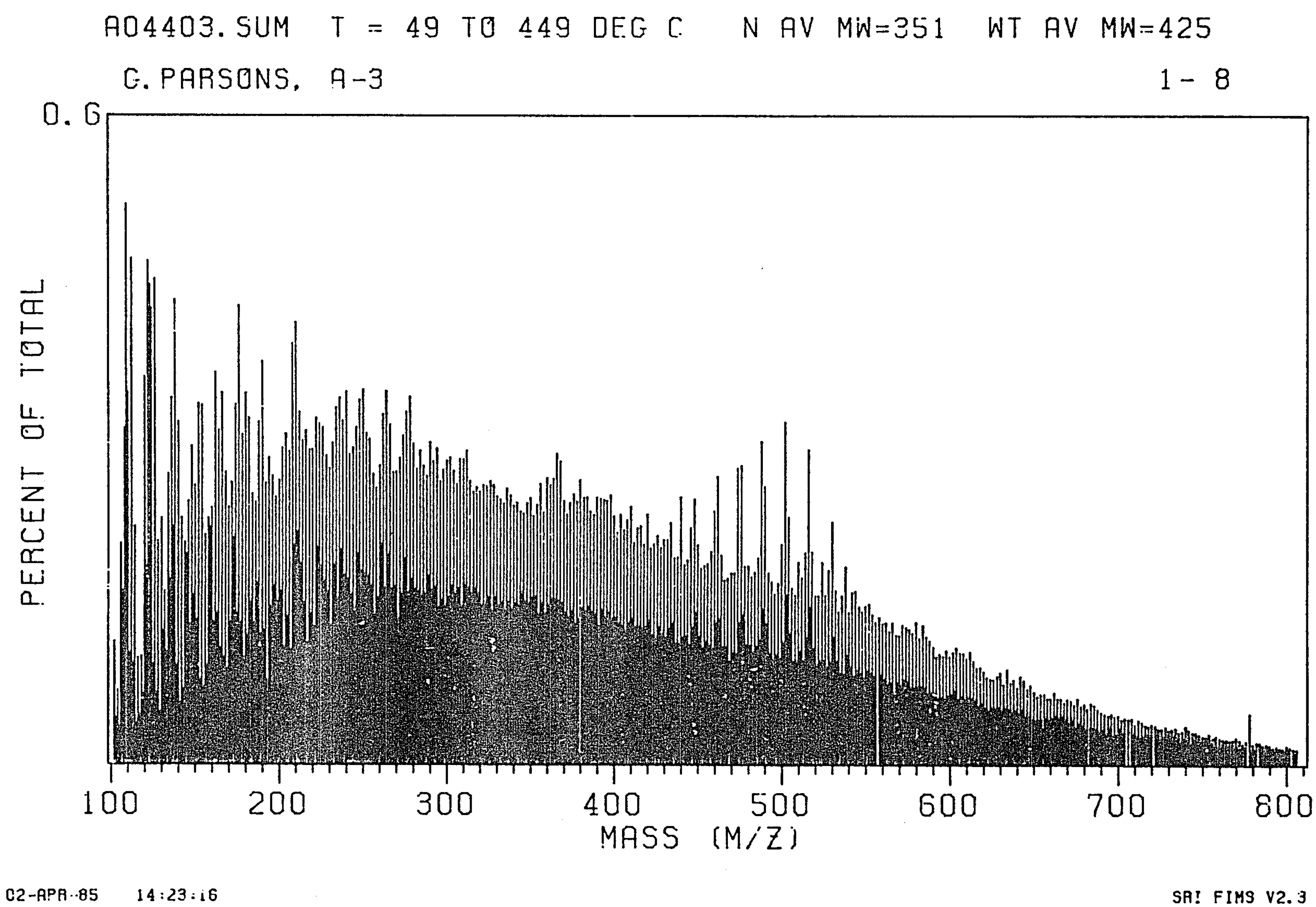


Figure 2. A histogram plot obtained from the FIMS data.

oxidants contained in seawater, the hydrocarbon reservoir contains mostly simple acyclic and monocyclic hydrocarbon chains. However, during natural maturation, reducing agents in seawater change many simple organic chains into more complex polycyclic and polynuclear forms. This process creates a complex mixture that was reflected and can be plotted in the FIMS histogram.

In the FIMS histogram, each peak represents an infinite number of hydrocarbon compounds that can be divided into 14 aromatic components (Figure 3). From these, the three unsaturated components that best represent each MB Chert source are the U1, U2, and U3 compounds (Figure 4). Of these, the single most optimal characteristic and reliable component was the U1 trace. When comparing histograms of SUM spectra, if two or more samples produced similar patterns, further reduction of the data was necessary. In these cases, the FIMS data was replotted three-dimensionally by its thermal ranges (Figure 5). This additional step in data reduction creates a more specific picture of the hydrocarbon content within MB Chert.

FIMS techniques are well-established tools in the fields of materials research, oil exploration, and petroleum manufacturing. They are used to fingerprint and map specific oil reserves and for tracing manufactured petroleum products back to their sources. Applying FIMS analyses to all known geologic occurrences of MB Chert in Central California revealed an interesting trait. All of the MB Chert sources examined exhibited unique fingerprints. Theoretically, this means that any MB Chert found out of its

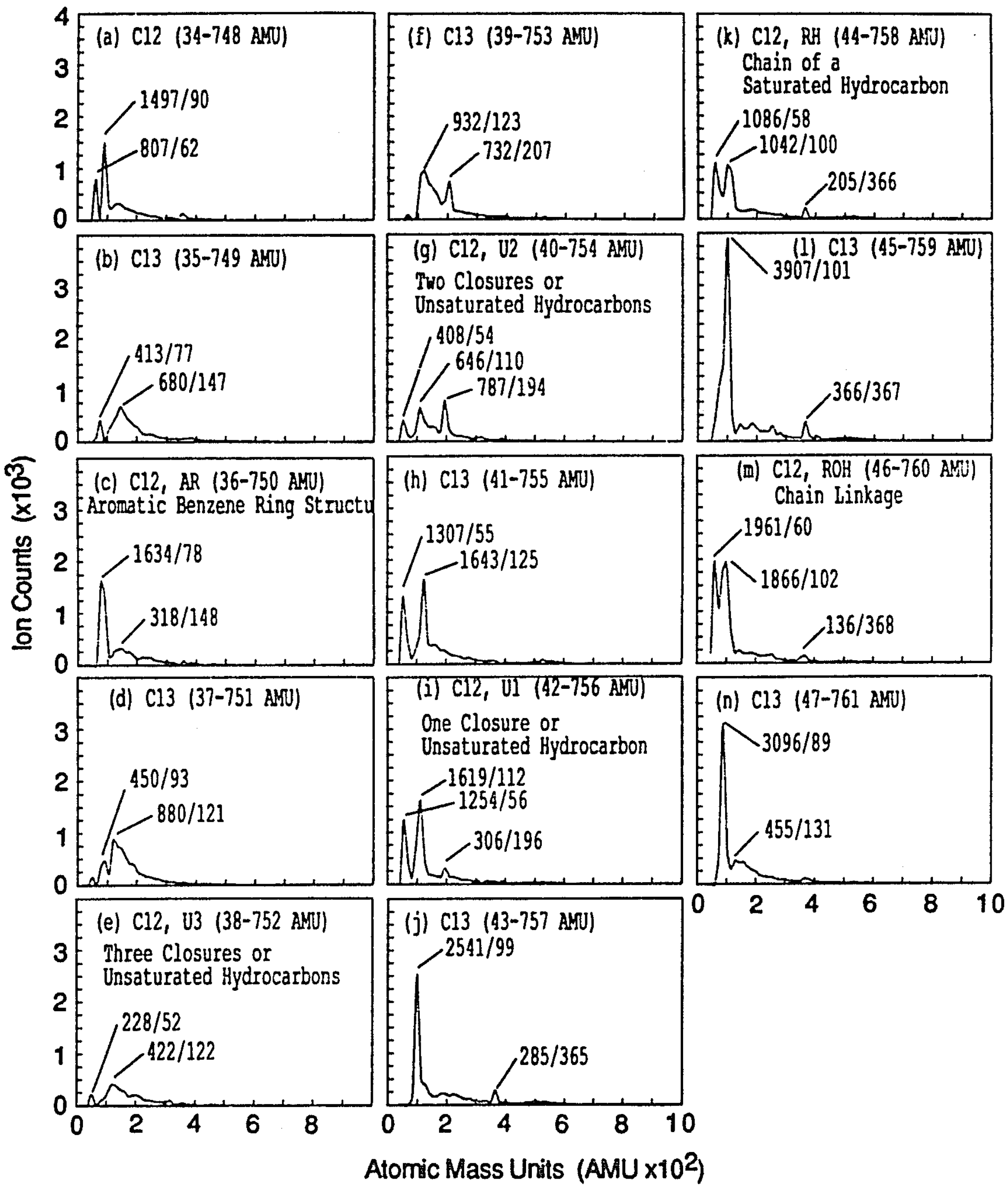


Figure 3. A FIMS sum spectra, separated into it's 14 basic components of bituminous aromatic hydrocarbons.

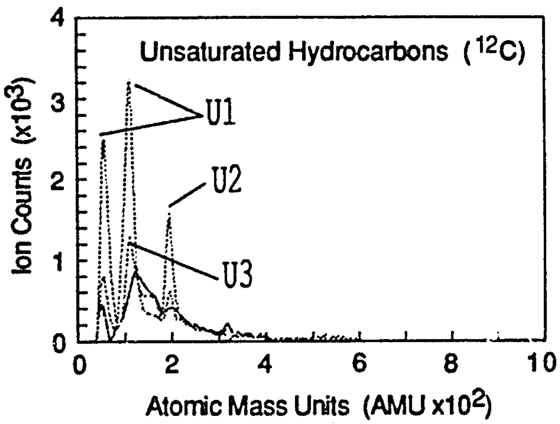


Figure 4. Three of the most typical and consistent FIMS components of unsaturated hydrocarbons contained within bituminous materials.

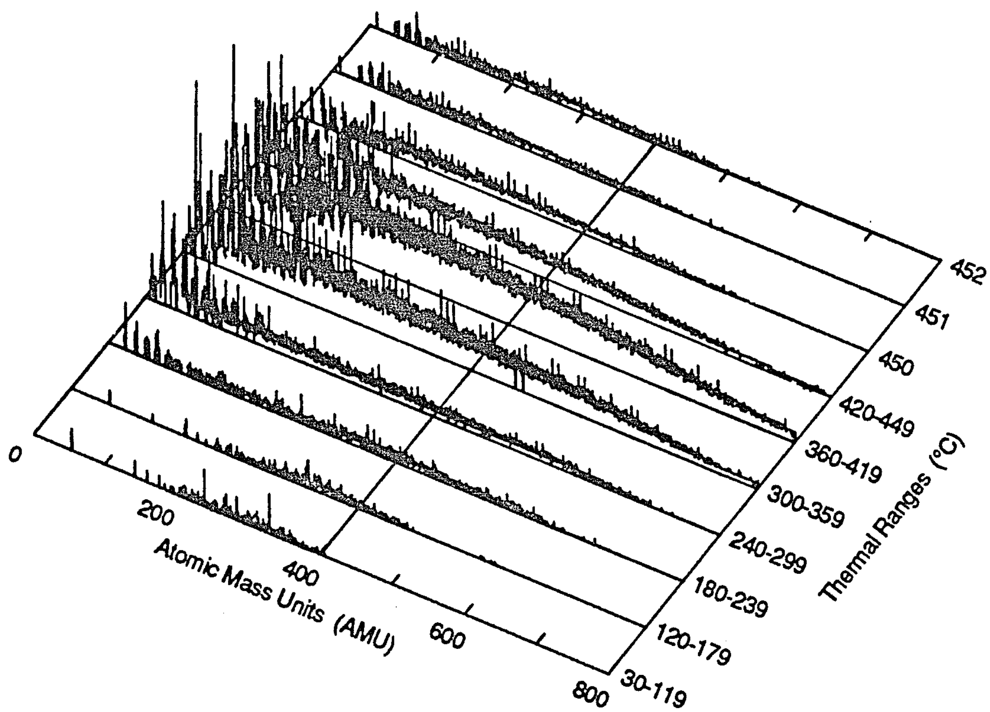


Figure 5. Three-dimensional plot of a FIMS sum spectra, separated by its thermal ranges.

natural environment can be traced back to its geologic point of origin. Therefore, FIMS can provide an excellent archaeological tool for the sourcing of MB Chert. Important questions nevertheless remain in the minds of most archaeologists; Can this technique reliably source all or most archaeological materials made from MB Chert? And, will it be useful and practical for following such artifacts through time and space?

Background and Purpose

The fundamental problem addressed in this study originated with the prehistoric use and exchange of MB Chert within the San Francisco Bay Area. MB Chert must have been a favored lithic material over the locally available and more abundant Franciscan Chert. This observation was based on the high frequency of occurrence within most archaeological sites. For the movement of coastal MB Chert inland, over the Santa Cruz Mountains, there must have been some interaction between widely separated prehistoric groups. To understand prehistoric lifeways and follow the interaction of one Native American group with another, it would be advantageous to fingerprint and source lithic materials in question. In an attempt to solve this complex problem, relatively new geologic techniques of analysis are employed. However, basic questions remain: Can MB Chert be fingerprinted and how? Once this problem has been solved geologically, can this newly acquired knowledge be applied to sourcing artifacts manufactured from MB Chert?

If the sourcing of MB Chert is successful, and proves to be a reliable technique, it would give archaeology another useful tool.

Before the introduction of sophisticated laboratory techniques, geologists and archaeologists had to rely on standard field techniques of observation to source lithic artifacts (Fleming 1976; Tarbuck and Lutgens 1984). These methods were sometimes questionable and often inaccurate. Through the application of newer, more advanced laboratory techniques of analysis, a more accurate interpretation of prehistorically traded goods became possible (Thomas 1979). Another author states that:

> Between the turn of the century and 1945, most archaeological investigations were exploratory: sites were excavated mainly to discover their depth, composition, and contents, rather than to seek answers to research questions. Archaeologists were concerned for the most part with learning the age of the deposit and whether any sort of cultural sequence might be inferred. Archaeology in Central California has advanced since 1950 in several important respects. This period witnessed improved field methods, the advent of radiocarbon dating, the introduction of obsidian hydration dating, and a growing interest in prehistoric cultures, ecology, and social organization. Radiocarbon and obsidian dating have led to precise absolute chronologies that permit synchronic comparisons as well as refined diachronic studies (Moratto 1984).

However, drawbacks to these procedures were that most applied only to primary organic substances, crystalline minerals (e.g., opalite, quartz, and red ocher made from cinnabar or hematite), and amorphous substances (e.g., obsidian). In the past, sourcing of obsidian artifacts with XRF has proven to be an extremely useful tool for establishing prehistoric socioeconomic patterns. Therefore, the principal of sourcing should be expanded to include other lithic materials, where possible.

It was noted that prior to the 1980's, many archaeological reports concerning the coastal areas of Central California, were deficient in the area of lithic research. Excluding raw counts, extensive classification, detailed typologies, wear patterns, and obsidian studies, a neglected area of research was the chipped stone constituents recovered from archaeological sites. Other than formed tools, few authors sufficiently analyzed or properly described lithic materials. Early reports often omitted the tabulated results of recovered lithic debitage, even though they constituted the majority of recovered material (Jackson 1974). Many archaeologists may not entirely agree with the above statements. However, they do admit this may have been true 10 or 15 years ago.

Until recently, other than obsidian, many chipped stone artifacts could not be adequately sourced. Therefore, only descriptions, typologies, associations, gross physical traits, and possible uses of these items were provided in many recent archaeological reports. Obsidian and a few unique materials were an exception to this principle. With the advent of more sophisticated equipment and laboratory techniques, not only obsidian, but now most hydrosilicates can be sourced accurately.

Significance of the Study (Hypothesis)

Established models can be modified and applied to new areas of research, such as this study. Scientific method states that (Longwell and Flint 1965; Hildebrandt 1981):

- All of the known facts within the problem are set down;
- Based upon the known facts, a hypothesis of possible relationships can be established, tested, and modified;
- Consequences are generated from the hypothesis by a bridging argument, and new theories established by analytical verification.

Although this study concerns the sourcing of MB Chert for archaeological purposes, the model was based on numerous geologic processes. One of these processes is: hydrocarbon (petroleum) deposition within MB Chert occurred concurrently with both chemical and biological deposition of silica. Based upon the geologic evidence, deposition occurred in an oxygen-minimum zone, within a back-ark basin, and in a relatively calm environment.

If interpretation of the geologic evidence was correct, reconstruction of the paleoenvironment and depositional processes of MB Chert is as follows: over millions of years and as a result of tectonic activity, subduction zones, island-arks, and back-ark basins developed. As these evolved in southern California and moved up the coast of California, the depositional environment needed for the formation of MB Chert also migrated up the coast. As the optimal zone moved northward over millions of years, the depositional materials incorporated into MB Chert evolved through time. Even though two important geologic processes were acting concurrently, they are discussed separately. First, the tectonic subduction of a major plate, thus creating volcanic island-arks and back-ark basins. Second, the creation of the San Andreas Fault System and thus movement of a crustal block northward from Mexico.

The hydrocarbon model suggested two extremes. First, MB Chert formed in southern areas would be older, contain remains of terrestrial desert-type ecosystems, and early forms of marine fossils. Early hydrocarbon deposition would result in a unique complex of fossils and petroleum. Second, MB Chert formed in northern areas would be younger, contain remains of terrestrial forest-type ecosystems, and later forms of marine fossils. Later hydrocarbon deposition would result in an entirely different and unique complex of fossils and petroleum. All MB Chert created between these two extremes would have proportional amounts of both of the hydrocarbon complexes. These varying amounts of marine and terrestrial hydrocarbon would potentially have unique and detectable traits.

Previous Research

Many investigations have studied the fingerprinting of aromatic saturates (hydrocarbons) contained within crude petroleum, their trap rocks, and source formations. Some of these fingerprinting studies involved the following:

- Identification of oil spills and mineral oil effluents (Kikuchi et al. 1983);
- Use of optical rotary dispersion (Chandra et al. 1980);
- Gas chromatography (Douglas and Grantham 1974);
- Liquid chromatography (Angelin et al. 1983);
- Photochemical reactivity (Wakamatsu et al. 1984); and
- Chemiluminescence in autoxidation (Spilner, Ilgvars, and Hedenberg 1985).

These fingerprinting projects employed many new techniques, and each analysis was relatively successful in its own right. However, none was as sensitive or comprehensive as FIMS for the identification of aromatic bituminous material (Buttrill and St. John 1980). As far as can be determined, no published papers exist concerning the sourcing of chert in general, or MB Chert in particular. However, many papers deal with sourcing of other materials used by earlier cultures:

- Materials Issues in Art and Archaeology (Sayre, Vandiver, Druzik, and Stevenson 1988);

- The Economics of Obsidian in Central California Prehistory: Applications of X-ray Fluorescence Spectrography in Archaeology (Jackson 1974);
- Advances in Obsidian Sourcing by Non-Destructive Energy Dispersive X-ray Fluorescence (Hughes 1988);
- A New Technique for Identifying Prehistoric Features by Means of Soil Analysis (Dallas 1985);
- The Use of Asphaltum Sourcing in Archaeology (Gutman 1979);
- High-Tech Sleuths Take on The Art Forgers (Dornberg 1985);
- Elemental Analysis of Geological and Archaeological Specimens of Mayan-Blue Dye and Pottery Sherds From The Yucatan (Parsons 1986b);
- Maya Blue: A Solved Problem in Ancient Pigments (Torres 1988); and
- The Elemental Analysis of Marine Flora (seagrass and kelp) from CA-ORA-281 (Parsons 1985).

Statement of Tasks

This research project was designed to expand an earlier feasibility study (Parsons 1980) and to refine the techniques used for sourcing. In addition to examining MB Chert for gross physical traits, the following laboratory techniques were used: scanning electron microscopy (SEM), energy dispersive x-ray (EDX), x-ray diffraction (XRD), x-ray powder diffractometry (XRPD), crystallinity index (CI), thermogravimetric analysis (TGA), and field ionization mass spectrometry (FIMS).

Opon establishing and assessing the feasibility of sourcing MB Chert was accomplished, the secondary goal was to describe the archaeological diffusion of MB Chert throughout Central California. Data needed for this phase could only be gathered through a combination of field surveys, review of lithic collections, and the application of new laboratory techniques. MB Chert samples from all known geologic sources were collected and extensively studied to establish standards for each geologic source. Only after the fingerprints of geologic sources were well-established, could data obtained from artifactual materials be used to assign geographic origin.

Central California's coastal range was selected for this study because of its unique tectonic activity. The boundary between Pacific and American plates, known as the San Andreas Fault System plays an important role in California's geology and the geologic formations under study. The fault system divides the Monterey Shale Formation in half in a right-lateral fashion. The only segments of Monterey Shale Formation occurring in Central California are located west of the fault zone. This formation is the sole source of true MB Chert in Central California. Its nearest eastern compliment is in southwestern San Joaquin Valley, east of the San Andreas Fault Zone. However, this does not consider other Monterey Group Formations located within the coastal areas of Central California. These formations produce a good quality black Monterey Group Cherts and Chalcedonies, not true MB Chert.

Phase 1: Survey for Geologic Sources of MB Chert. The purpose of Phase 1 was to survey Central California for geologic occurrences of MB Chert. Initially, the survey area extended from northern Mendocino County to southern Monterey County, and from the Pacific Coast to the Sierra Nevada Mountain Range (Figure 6). To refine and reduce the survey area, the parameters of known MB Chert sources were compiled to determine unlikely areas. In searching for MB Chert sources, a few important questions arose:

- What formations were associated with MB Chert?
- What were the geologic ages of the host formations?
- What rock types were the host formations?
- Were there any associated bituminous outcroppings near a source?
- Were the host formations siliceous?
- Were the host formations marine or nonmarine origin?
- What were the ages of associated microfossils? and
- What influence does the San Andreas Fault have on lithic sources?

In this first task, all potential areas of Central California were surveyed for any occurrence of Monterey Chert. All chert sources located were recorded and mapped. Samples of native rock were collected from each location to supply the analytical tests with raw materials. The second task entailed testing of the samples. The following tests were designed to determine whether MB Chert contained unique qualities. Of the five tests, the first three were to confirm whether or not a particular sample was MB

Chert. The last two tests were designed to complete the fingerprinting process. The five tests were:

- SEM - to inspect internal structures of MB Chert and other hydrosilicates for unique features;
- EDX - to show the elemental content of MB Chert and other lithics for possible trace elements;
- XRPD - to reveal the mineral content of chert specimens and to compute their crystallinity index;
- FIMS - to determine the organic content of MB Chert and associated lithic materials; and
- TGA - to record relative loss of volatile components within MB Chert.

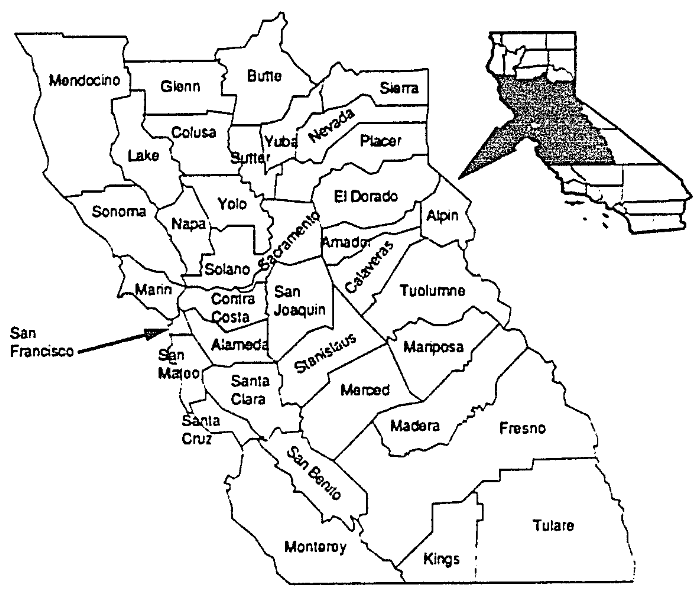


Figure 6. Adopted study area for the geologic sourcing of Monterey Banded Chert within Central California.

<u>**Phase 2: Archaeological Distribution of MB Chert.**</u> The purpose of the review phase was designed to establish the approximate prehistoric distribution of MB Chert inland. The purpose of this task was to determine the simple presence or absence of MB Chert within archaeological sites throughout Central California. Central California was chosen because of the known tendency for prehistoric trade networks to migrate material east-west rather than north-south (Layton 1980). Public and private collections were scrutinized and all MB Chert specimens were recorded, photographed, and samples were obtained for further analysis.

<u>**Phase 3: Sourcing of Prehistoric MB Chert Tools.**</u> After establishing fingerprints of known MB Chert sources, chert artifacts from archaeological sites immediately adjacent to these sources were also sourced. The original goal of Phase 3 was to obtain at least one MB Chert artifact, flake, or piece of debitage from each archaeological site reviewed in Phase 2. However, due to the high cost of testing, specimens from only a few local sites and the most distant sites were analyzed. The local sites selected were immediately adjacent to major sources of MB Chert. All MB Chert artifacts chosen for testing were subjected to the analyses described in Phase 1.

<u>**Phase 4: Analysis of Thermal Traits.**</u> It is well-known that prehistoric cultures around the world thermally altered lithic materials before or during the manufacture of chipped stone tools (Rick and Asch 1978). Thermal alteration of MB Chert could affect its chemical composition and

thus have an adverse effect on the ability to source an artifact. Physical evidence within coastal middens suggests that thermal alteration was a common practice in Central California (Parsons 1987). Therefore, a thermal study was begun to determine to what extent the hydrocarbon content changed as a result of the heating-treating process.

CHAPTER II: GEOLOGIC BACKGROUND

Introduction

To understand the geographical distribution of naturally occurring Monterey Banded (MB) Chert, a general review of the geologic forces that created MB Chert is necessary. Several long-standing geologic reports were used in the organization of this study. These early works satisfactorily explained geologic features, the forces that created them, and formed the basis of the following discussion. To clarify the subject, many complex geologic processes have been simplified and were at the mercy of this author's interpretation of the data. While many tectonic forces affect California's topography, only those having a direct bearing on the sourcing of MB Chert are described.

Classifications used in this report fall into three categories: chronostratigraphic, geochronological, and lithostratigraphic. Classifications are needed to organize similar strata of persistent sequences into named units representing principal variations of closely related rock units. The importance of definitions is not fully appreciated until geologic mapping, cross sections, and field surveys are undertaken (Longwell and Flint 1965). The above classifications are relatively common in geology and the criteria for describing them are well-established by the International Subcommission on Stratigraphic Classification (Hedberg 1976). Before the advent of absolute dating techniques, geologists and archaeologists relied on the laws of superposition and association to describe and plot formations (Tarbuck and Lutgens 1984).

This chapter is divided into five fundamental categories: plate tectonics, faulting, Monterey Formations, Monterey Cherts, and the formation of bituminous substances. Even though each geologic process is described separately, these forces operate concurrently and their spheres of influence are closely interrelated. Geologic forces do not operate independently; each is the result of other geologic interactions and, in turn, affect still other geologic processes.

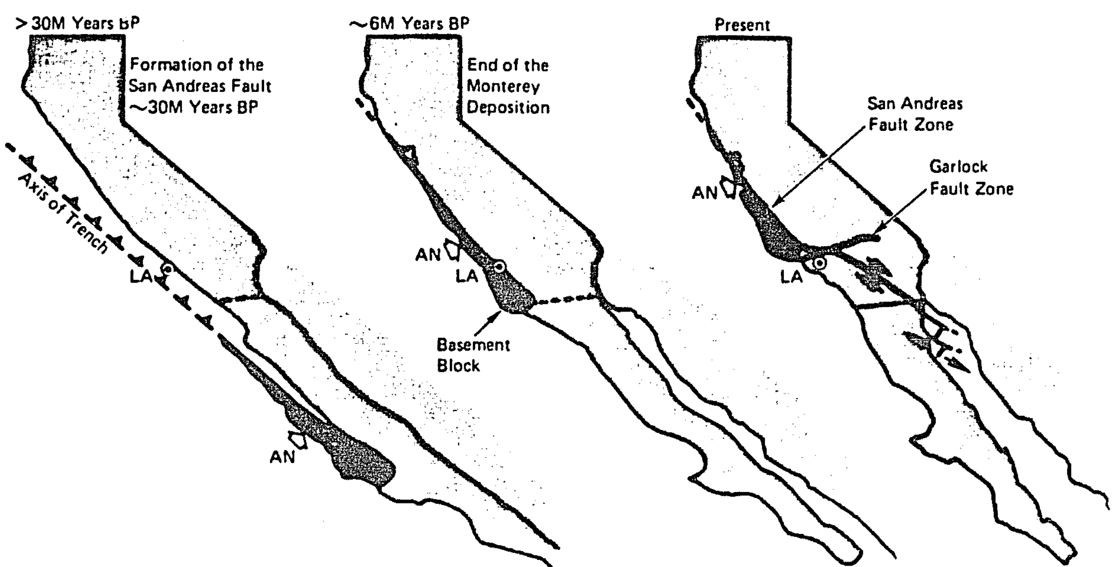
Plate Tectonics

Approximately 30 million years ago, a segment of the East Pacific Rise was located west of California's archaic coast. The East Pacific Rise was a divergent fracture in the earth's crust, which separated and forced apart two major tectonic plates (Tarbuck and Lutgens 1984). Strong convection currents deep within the earth's mantle move the various segments of the earth's crust at unequal rates, thus causing strenuous stress. This stress created transform faults perpendicular to the spreading zones to accommodate the unequal divergence. This mechanism allows tectonic plates to move past each other at unequal rates. The East Pacific Spreading Zone diverged at approximately 3-10 cm per year (Tarbuck and Lutgens 1984).

The San Andreas transform fault allowed, and still allows, the two plates to pass each other at 2.7 cm per year, right laterally (Foothill 1975).

The East Pacific Rise, off Central California's archaic coast, was being subducted at a greater rate than it was diverging. This indicated that the Farallon Plate, on the east side of the rise, was being subducted beneath the lighter North American Plate. As the denser Farallon Plate plunged back into the earth's mantle, it was reabsorbed (Tarbuck and Lutgens 1984). This tectonic action caused a multitude of secondary effects, including (Figure 7):

- The separation of Baja California from mainland Mexico;
- The expansion of the Gulf of California; and
- The creation of deep marine trenches parallel to California's archaic coast.



Source; Tarbuck 1984

Figure 7. Tectonic movement of the crustal block under study, as described in the sourcing model.

As the Farallon Plate was subducted, its lighter material migrated upward from the remelting and erupted back onto the earth's surface. This created volcanic island-arcs just off-shore from California's archaic coast. This created back-arc basins between the mainland and island-arcs (Tarbuck and Lutgens 1984). Also as a result of the subduction, sedimentary surface materials were scraped off by the leading edge of the North American Plate. The action is analogous to scraping the icing off a layer cake with a brick. The scraping formed wedges of deformed marine sediments that became permanently welded to the leading edge of the North American Plate (Figure 8). This created the Franciscan-Knoxville Mèlange Formation that today makes up a large percentage of the Central California Coast Range (Bell 1939).

The subduction process and its island-arcs created sheltered inland seas, known as back-arc basins. Later, these deep basins were filled in with marine and terrestrial sediments that later transformed into rock that became known as Monterey Group (MG) Formations. Remnants of these island-arcs still existed as a string of dormant volcanic vents within the Central California Coast Range (Howard 1967).

As the East Pacific Spreading Zone itself became subducted, one of the transform faults, known as the San Andreas, broke off. The Pacific Plate rebounded back into its normal horizontal position and came into direct contact with the North American Plate. The Farallon Plate, east of the spreading zone, was completely subducted except for a small fragment known

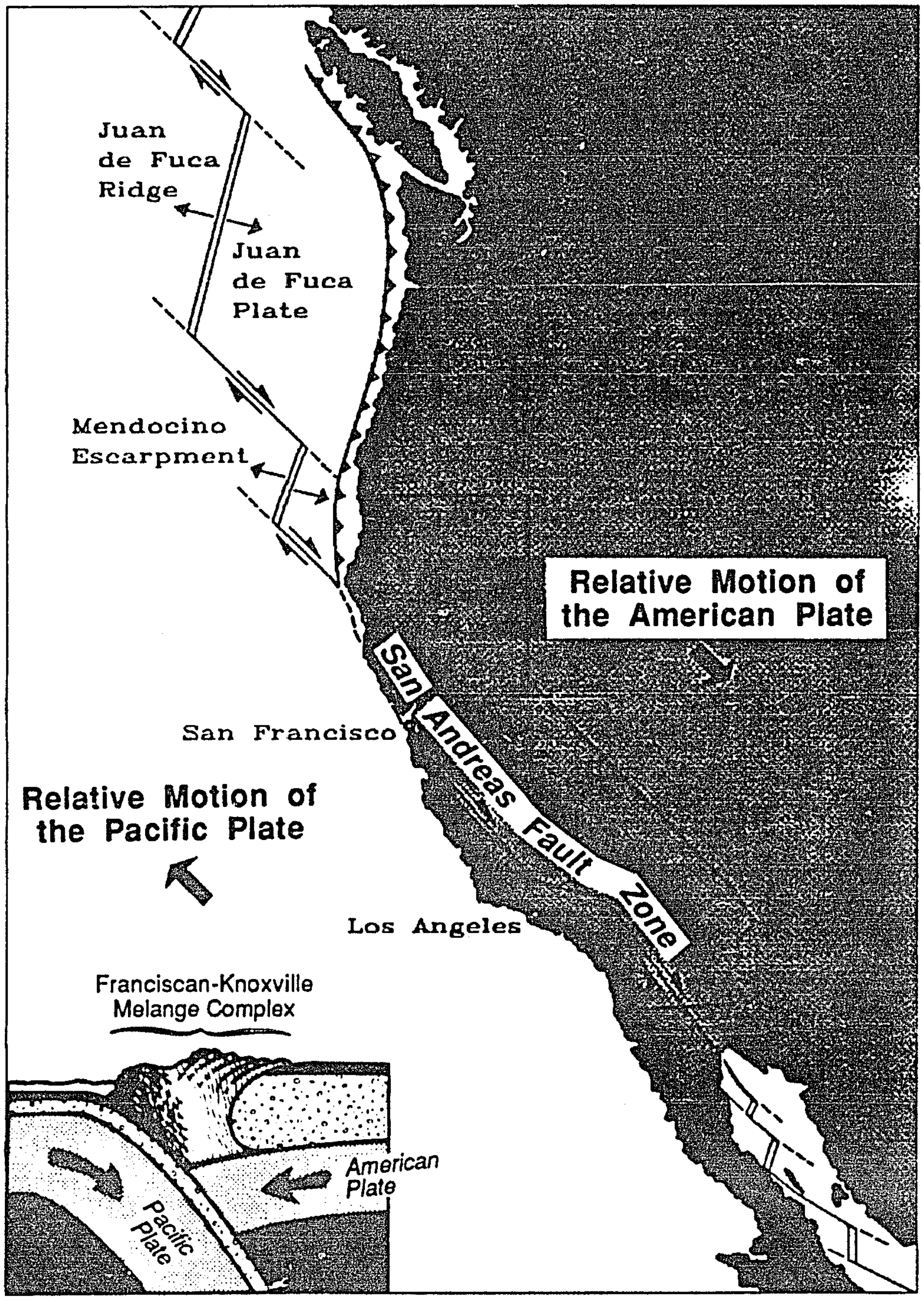
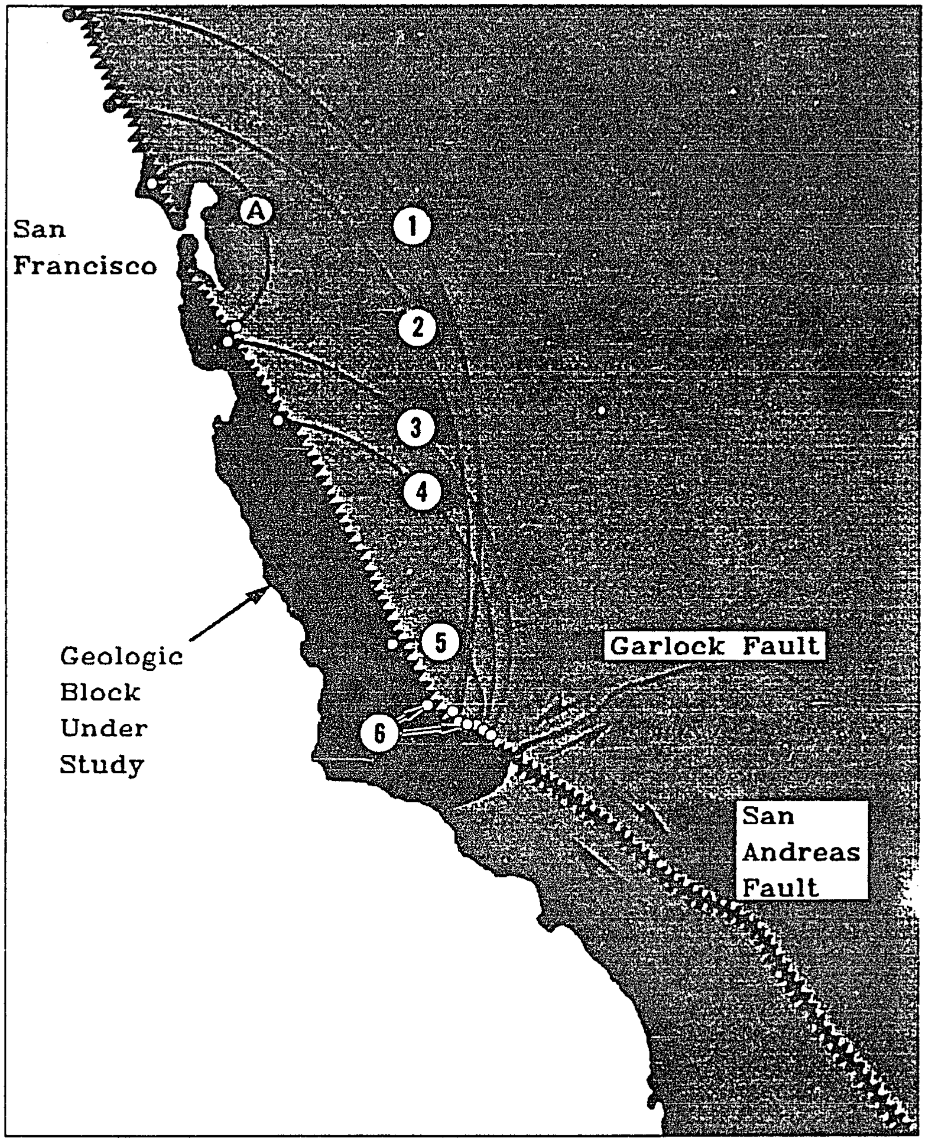


Figure 8. Tectonic interaction between subduction zones, spreading zones, convergent plates, and their influence on the West Coast of North America.

as the Juan de Fuca Plate. Also, in this same area, an active remnant of the East Pacific Rise still exists, known as the Juan de Fuca Rise (Figure 8).

Even though the subduction zone was parallel to California's archaic coast, the spreading zones themselves were being subducted in an oblique manner. This meant that island arcs and back-arc basins were progressively formed along California's coast. This process began in Mexico, worked its way up the coast, presently resides off the west coast of North America, and continues to be active (Tarbuck and Lutgens 1984).

During the Middle Miocene, Baja California was still connected to the mainland of Mexico (Figure 7). After the East Pacific Rise was subducted, a large block of crustal material became separated from Baja, due to continental divergence as the spreading zone passed beneath. This block was maneuvered northward (Figure 9) by the action of the San Andreas Fault System (Anderson 1971).



Source: Lacopi 1973, Clark 1984

Figure 9. Corresponding geologic evidence supporting progressive movement of the fault block up the West Coast of North America.

Faulting

Because of continental stress, the majority of California's numerous faults strike northwest-to-southeast, parallel to the San Andreas Fault Zone. Faults can shift in any one or a combination of directions. The four fundamental fault types are the normal or dip-slip fault (divergent), reverse or thrust fault (convergent), right or left lateral strike-slip fault, and the oblique-slip fault having both vertical and horizontal displacement (divergent or convergent) (Tarbuck and Lutgens 1984).

The fault movement that most significantly affects the formations currently under study was the right lateral motion of the San Andreas Fault System. Considerable variations of relative displacement, ranging from a fraction of a millimeter to hundreds of kilometers have taken place along this fault (Figure 9). The San Andreas Fault System includes hundreds of splinter faults in addition to subordinate systems (Case 1963). A few of the major subordinate faults are: San Gregorio, Garlock, Hayward, and Calaveras Fault Systems. The San Andreas Fault System is unique in several ways (Lacopi 1972):

- It is one of the few plate contacts above sea level;
- Its surface trace is over 650 miles long;
- It is over 150 million years old; and
- It has caused major juxtaposition of rock features.

The sourcing model states, as the environment conducive to the formation of MB Chert progressed up the West Coast of North America, the sources of raw materials being deposited changed or evolved through time. As the crustal block moved northward, terrestrial and marine sediments were continually being deposited onto it. Geologic examinations of sedimentary rocks on either side of the San Andreas Fault Zone (Figure 9) supports this theory (Lacopi 1972; Clark et al. 1984).

Formations

Monterey Group (MG) Formations are typically thick, aerially extensive, and occupy a large percentage of California's land mass. This study also examined the geologic occurrences of Monterey Group (MG) Cherts, found exclusively within MG Formations. Most MG Formations in Central California are Middle to Upper Miocene Marine with a few intruding into the Early Pliocene. The most important of these is the Monterey Shale Formation with its unique MB Chert.

Monterey Shale Formation. The Monterey Shale Formation dates to the Middle Miocene (Weber & Cotton 1980; Weber, LaJoie, & Griggs 1979). It was named by Lawson in 1914 for its extensive beds of exposed siliceous shales near Monterey, California (Jenkins 1951; Case 1963). At the type locality near Monterey, California, the rhythmically bedded Monterey Shale Formation is divided into two foraminiferal divisions. They are the 2,835 foot thick, Upper Nonion Division and the 330 foot thick, Lower Valvulineria californica Division (Galliher 1930). The formation is characterized by extensive outcroppings of siliceous shales that are occasionally classified as porcelanite. Porcelanites usually occur as a porcelaneous shale or cherty shale (Pisciotto and Garrison 1981). The Monterey Shale Formation is characterized by extensive exposures of steeply dipping rhythmic beds of siliceous shale. The conspicuous rhythmic bedding of the formation is also reflected in its unique chert. Rhythmic bedding indicates a regular recurrence of depositional cycles of sedimentation (Bramlette 1946; Pisciotto and Garrison 1981). Three features of rhythmically bedded laminated shales are:

- First-order cycles are characterized by thin layers (0.4-10 mm) and were formed from the seasonal deposition (0-1 year).
- Second-order cycles are characterized by thick layers (1-100 cm) that formed over many years (2-200 years).
- Third-order cycles are characterized by very thick layers (1-5 m) and took thousands of years (1000-4000 years) to form.

Recently, the Monterey Shale Formation has received renewed attention because it is one of California's largest oil-producing trap-rock formations. The Monterey Shale Formation is extremely important to the petroleum industry and has been the subject of many comprehensive reports (Isaacs 1986). In Central California, the Monterey Shale Formation lies nonconformably on granitic basement rock. It is unconformably overlain by the Santa Margarita Bituminous Sandstone, Santa Cruz Mudstone, and

Purisima Sandstone Formations (Clark 1981; Clark et al. 1984; Addicott et al. 1978).

As stated earlier, many conditions required for the creation of Monterey Shale and its unique chert evolved as the depositional environment progressed up the west coast of North America. This created many depositional environments in which Monterey Shale, MB Chert, and its associated petroleum could evolve (Blake 1981; Ingle 1980). Four depositional environments were reflected in its lithic record (Pisciotto and Gerrison 1981). These four environments are the upper slope of the outer shelf, isolated bank-top, aerated basin, and anoxic basin.

In this study, important features and microfossils were detected after analyzing 360 samples of MB Chert from Central California using scanning electron microscopy (SEM). A sufficient number of organisms were identified to enable the reconstruction of the depositional environment. MB Chert samples contained nearly equal amounts of both terrestrial and marine organisms. From this observation, the petroleum contained in MB Chert fell into the Type II Kerogen category (Kablanow II and Surdam 1983; Philp 1986).

As stated earlier, in Central California the Monterey Shale Formation, that yields true MB Chert, is divided into two foraminiferal divisions at its type locality near Monterey, California, the upper Nonion and the lower Valvulineria californica (Galliher 1930). Benthonic marine organisms found within a number of MB Chert samples from Año Nuevo established the cherts point of origin well-within the lower Valvulineria californica division. The lower 330 feet of the Monterey Shale Formation, is also called its basinal unit, and comprises three facies: the upper siliceous, the middle phosphatic, and the lower calcareous facies (Obradovich & Naester 1981; Pisciotto & Garrison 1981). After further SEM examination of MB Chert samples from Año Nuevo, the presence of benthonic microfossils within the chert suggested the following:

- The Monterey Shale Formation is the sole source of true MB Chert;
- MB Chert was formed within a deep marine oxygen-minimum zone, 500-1000 meters beneath the surface of the ocean;
- MB Chert originated in the upper siliceous facies of the basinal unit;
- The Monterey Shale Formation dates to the Middle Miocene;
- The basinal unit was formed within an anoxic back-arc basin; and
- MB Chert was formed in close association with known petroleum reserves.

Similar tectonic forces are creating the same chert forming conditions off the southwest coast of Alaska. This deep and relatively calm back-ark basin exists between the Aleutian Island chain and the mainland of Alaska (Tarbuck and Lutgens 1984).

Petroleum Formation

This study involves the fingerprinting of unique petroleum fractions contained within MB Chert. Therefore, this organic substance and its formation will also be described in this report. Petroleum was formed from the deposition of organic debris, such as marine plants, algae, bacteria, fungi, phytoplankton, megafossils, and innumerable microscopic organisms, into deep marine sediments. About 99% of all organic debris was destroyed during the settling process and initial stages of deposition. Decay was accomplished by low-temperature chemical oxidation or microbacterial attack during the materials slow descent to the sea floor. However, only 1% of the surviving detrital material was ever actually incorporated into sedimentary rock. And only a small fraction of this material was ever altered further into a fossil fuel, such as petroleum. The extent and rate of degradation depends on whether or not the environment of deposition was oxic or anoxic. In oxic waters, organic debris was rapidly destroyed, and very little organic material was altered into petroleum. However, in waters that were anoxic, organic debris was more likely to be preserved (Philp 1986).

In either environment, further degradation could be enhanced by the action of turbidity currents, bioturbation, or benthonic scavengers. These disturbances facilitated the diffusion of oxidants throughout the surface and near-surface sediments. This action promoted the further breakdown of organic material by oxidation. Thus, an anoxic environment could prolong degradation for hundreds or thousands of years. Conversely, an oxic environment hampers the preservation and accumulation of these organic materials. In spite of many obstacles, a considerable amount of organic material manages to survive long enough to become deeply incorporated into bottom sediments. However, this material still had to undergo additional reactions and alterations caused by thermal maturation to become a fossil fuel (Philp 1986).

Thermal maturation is restricted to temperature ranges above 50°C. The first step of this unique process of transformation is called diagenesis. As organic material was buried ever deeper by the additional deposition of tons of organic debris, temperatures increased proportionally from 50-200°C. The heat and pressure transformed organic material into fossil fuel and is called a catagenesis. Even deeper deposits, thermal ranges increased to >200°C where fossil fuels were transformed into methane gas and graphite, this process is known as metagenesis (Philp 1986).

Chert Formation

The formation of chert can be a complicated process to understand and a geologic definition of this material would be helpful. The term chert is used for a variety of dense, hard, and siliceous sedimentary rocks whose dark earthy colors were derived from chemical impurities (Tarbuck and Lutgens 1984). The majority of cherts are composed of microcrystalline or cryptocrystalline hydrosilicates (Briggs 1957). The term flint is synonymous with chert. In 1938, many geologists suggested that the term flint should be eliminated from the geologic vocabulary and reserved for Old World artifactual materials. However, this verbal convention was already being adopted by many anthropologists (Pettijohn 1957). Chert is polygenetic, it has no single mode of origin, however, only two types of chert formation will be described. The first method is the chemical (inorganic) deposition of precipitated colloidal silica. The second method is the biological (organic) deposition of detrital material (Figure 10).

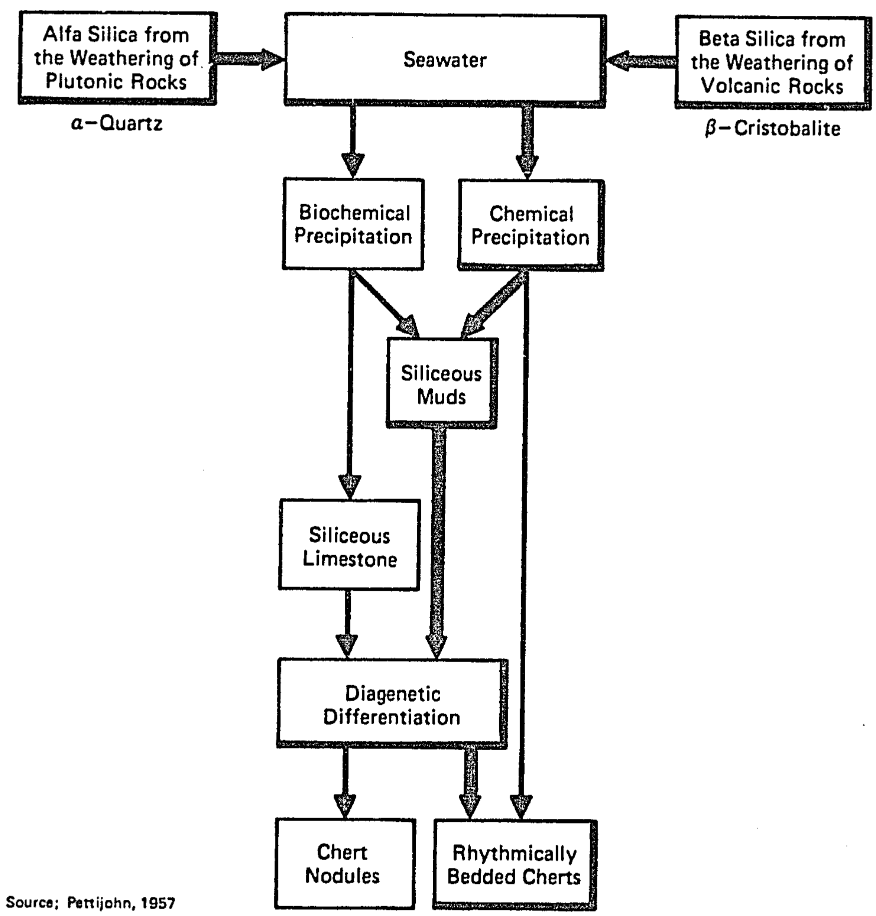


Figure 10. Generalized block diagram depicting two modes of hydrosilicate (chert) formation.

Chemical Deposition. Chemical deposition begins by the weathering of granitic and volcanic formations rich in silicate minerals, like California's Sierra Nevada Range. Silica is liberated from minerals such as potassium feldspar by the mechanical breakdown of parent rock by frost and root wedging, exfoliation, and spalling. This breakdown creates a greater surface area on which chemical weathering can take place, and chemical weathering eventually produces kaolinite (clay). These minerals are acted upon by natural caustic agents such as humic or carbonic acid, eventually liberating silicates into solution. Silica is then secreted into ground water, leached into streams, and transported downhill by gravitational forces. It is eventually carried into the sea (Figure 10) (Tarbuck and Lutgens 1984).

Dissolved silica is then deposited by the following process. Silica-laden fresh water flows from the mountains into saltwater bays, estuaries, or deep water environments. Salt within seawater acts as a catalyst, causing destabilization of suspended silicate ions. This triggers the suspended silica and other substances to precipitate out of solution as cryptoscopic colloidal particles. This perpetual process eventually forms a colloidal sludge (mud) at the bottom of the sea (Tarbuck and Lutgens 1984). Most colloidal particles range from 7-40 μm in diameter with silica concentrations between 20-50% (Kirk-Othmer 1969). These extremely small particles have significantly different settling rates. A 7.0 μm sphere having a specific gravity of 2.0 in distilled water at 25°C will settle at 0.3 mm/sec (Appendix A). During precipitation, colloidal silica collects into gel masses, forming pockets or lenses of silica-rich material (Kirk-Othmer 1969).

Over millions of years, this material is transformed into chert by the heat and pressure generated by tons of additional material being deposited on top. Despite similarities of their basic properties, cherts are highly variable, even those from the same geologic source (Tarbuck and Lutgens 1984). Color variations are caused by trace elements and texture variations by crystallinity of the groundmass. Using Mohs' hardness scale of 1-10, most hydrosilicates have a hardness of 7.0-7.5 and specific gravities between 2.0-2.65 (Longwell and Flint 1965).

Biological Deposition. Biological deposition of siliceous materials are closely associated with bedded cherts. Many fossil remains are contained within most bedded cherts and their host formations. Biogenic silica is derived from numerous aquatic marine organisms such as diatoms, radiolarians, sponges, and silicoflagellates. These organisms manufacture solid amorphous silica out of solution in the form of shells (tests), skeletons, spines, sponge spicules, and plates. Most range from 2.0-300 μm in diameter. Their maximum settling velocity, under ideal conditions, is from 0.02-300 mm/sec (Appendix A). From the fossil evidence, it was determined that the depth of this decent is from 500-1000 meters, into the oxygen-minimum zone. Considering increased density of seawater due to depth, temperature, salinity, and currents, these organisms take years to reach the bottom of the sea.

Modern marine organisms are capable of extracting silica from the surrounding seawater containing as little as 0.1 ppm. These organisms occur in both marine and freshwater environments throughout the world and form a significant part of most marine sediments. Most biogenic silica (delicate opaline shells) is dissolved by cold acidic seawater long before they ever reach the bottom of the sea (Kirk-Othmer 1982). However, their silica is reprecipitated through chemical processes, thus cementing resistant debris. This process forms extensive shale beds that are typical of the Monterey Shale Formation (Bramlette 1946).

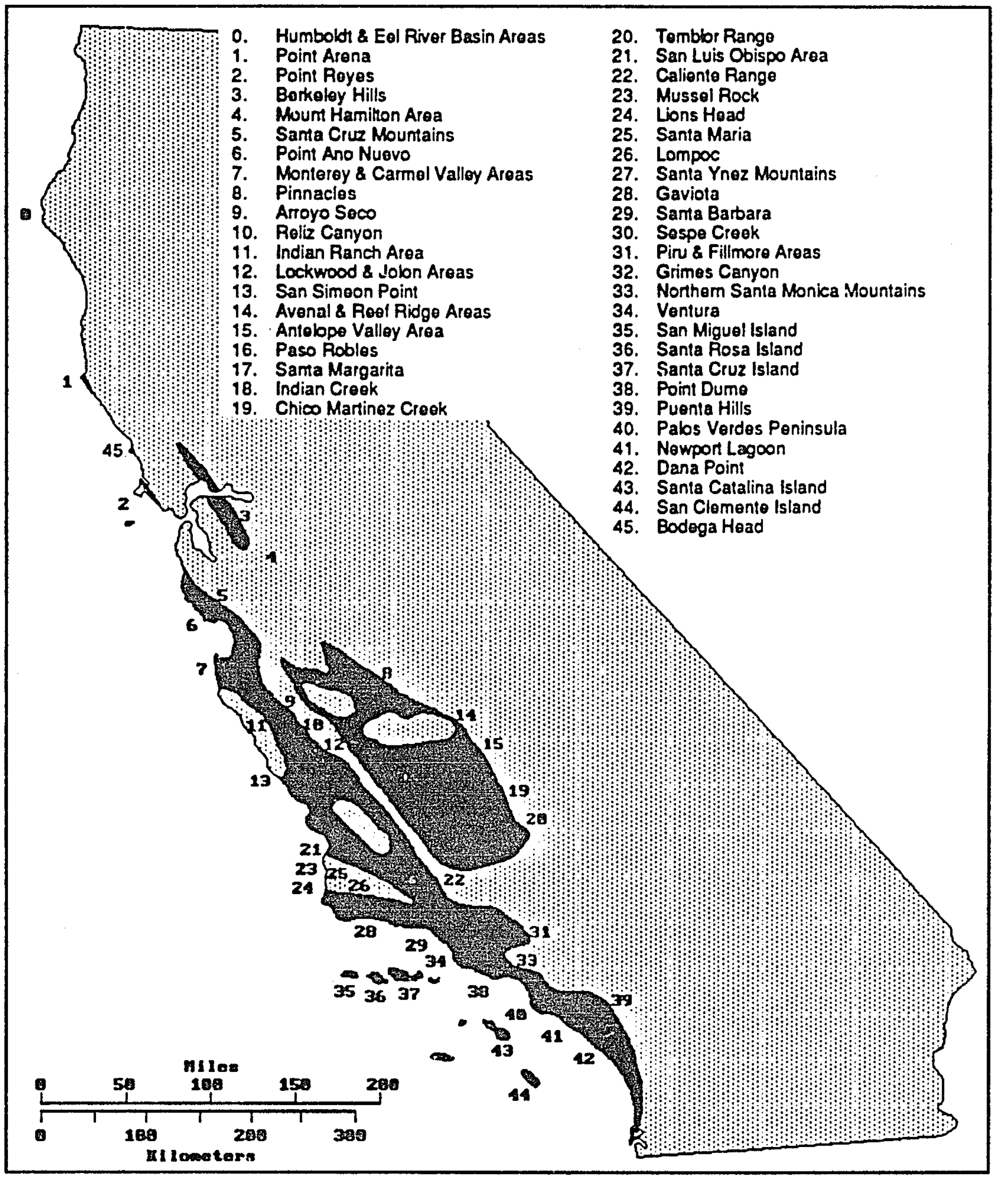
Dissolution is inhibited by several factors, thus allowing some delicate siliceous materials to survive long enough to reach the sea bottom. Some of the common factors are (Kirk-Othmer 1982):

- If small amounts of metallic ions are incorporated into the siliceous structure, the process of dissolution is inhibited.
- If siliceous tests could retain some of their external chitinous coatings, this could protect them long enough to reach the sea bottom.
- Most of these organisms were at the pinnacle of the marine food chain and were eaten by larger predators (fish). Their indigestible siliceous tests are eventually passed within fecal pellets. Fecal pellets protect their contents as they descend, thus allowing delicate structures to become incorporated into the sedimentation.

It is understood that all cherts are polygenetic, and there is no single mode of origin. The origin of each particular variety of chert will have to be established with the evidence at hand (Pettijohn 1957). The combination of crystallinity, impurities, density, degree of metamorphosis, and weathering have discernible affects on the cherts physical characteristics. The physical characteristics affect the workability of the stone and the resulting manufactured tool. These affect the size, shape, edge angle, use, and life of the product (Rick and Asch 1978).

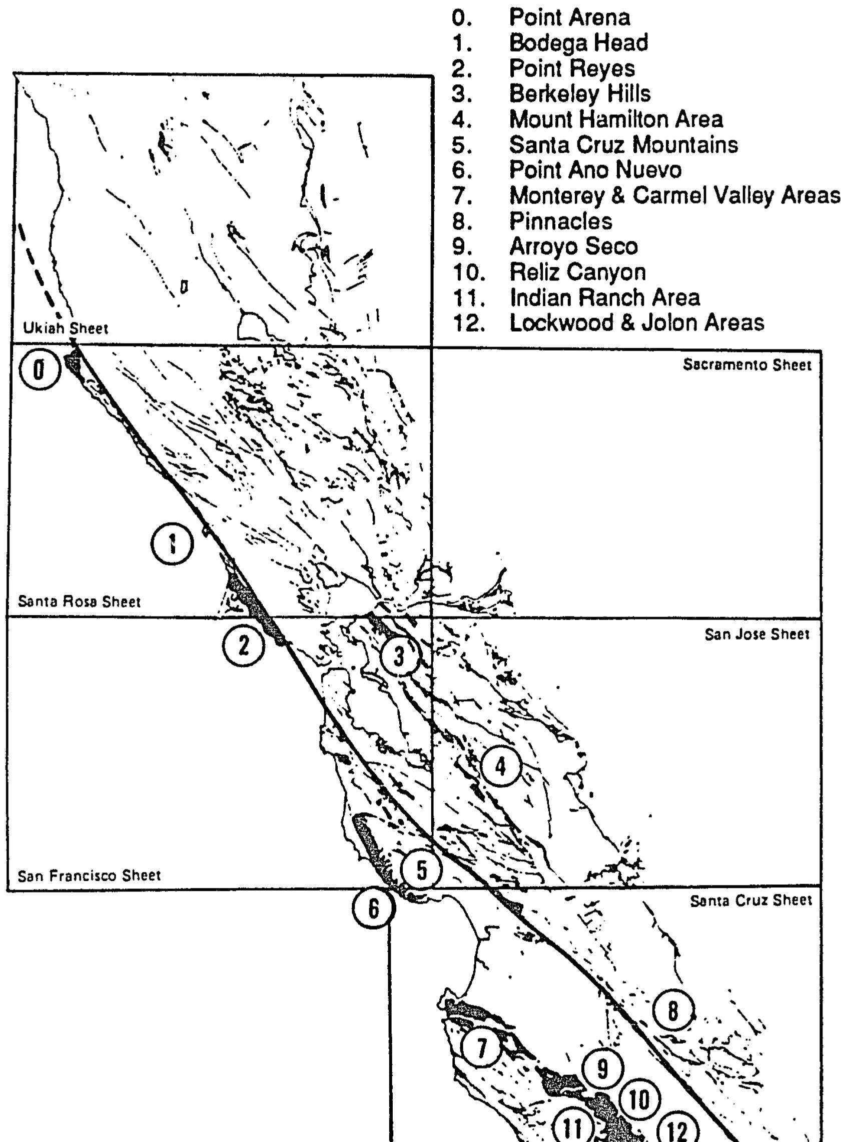
Geologic Source Information

For control of the large data pool available in studying color variations of MB Chert, only the black (dark brown) specimens were chosen for this study. After reviewing black chert sources in Central California, two characteristics became apparent: True MB Chert only occurred west of the San Andreas Fault Zone. And that black Monterey Group Cherts and pseudo-lithics occurred on either side of the fault zone. As stated previously, the initial survey area for possible geologic sources of MB Chert was reduced by a process of elimination. Using the Año Nuevo Point source area as a model, all known occurrences of MB Chert and its geologic associations were noted and recorded. All true MB Cherts were associated with: the deep marine Monterey Shale Formation (Figure 11), middle-to-late Miocene age (Figure 12), salacious shale members (Figure 13), and petroleum reserves (Figure 14).



Source: Obradovich & Naeser 1981

Figure 11. Generalized surface distribution of deep marine outcroppings of Monterey Shale Formations within California's Coast Range.



Source: California Division of Mines and Geology

Figure 12 Surface distribution of middle-to-late Miocene marine formations within Central California's Coast Range, dotted lines are faults.

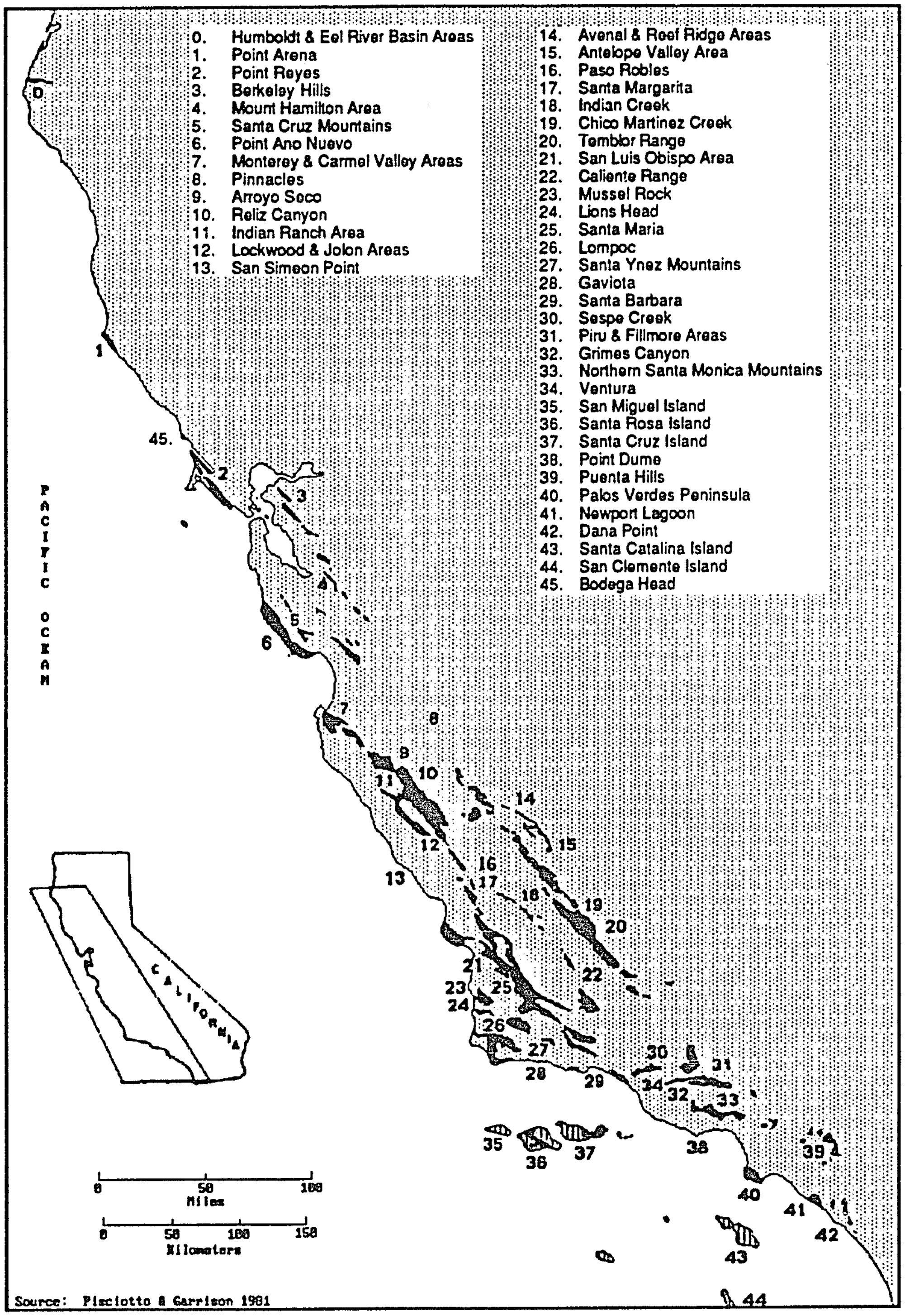


Figure 13. Surface outcroppings of siliceous shale found within Central California's Coast Range.

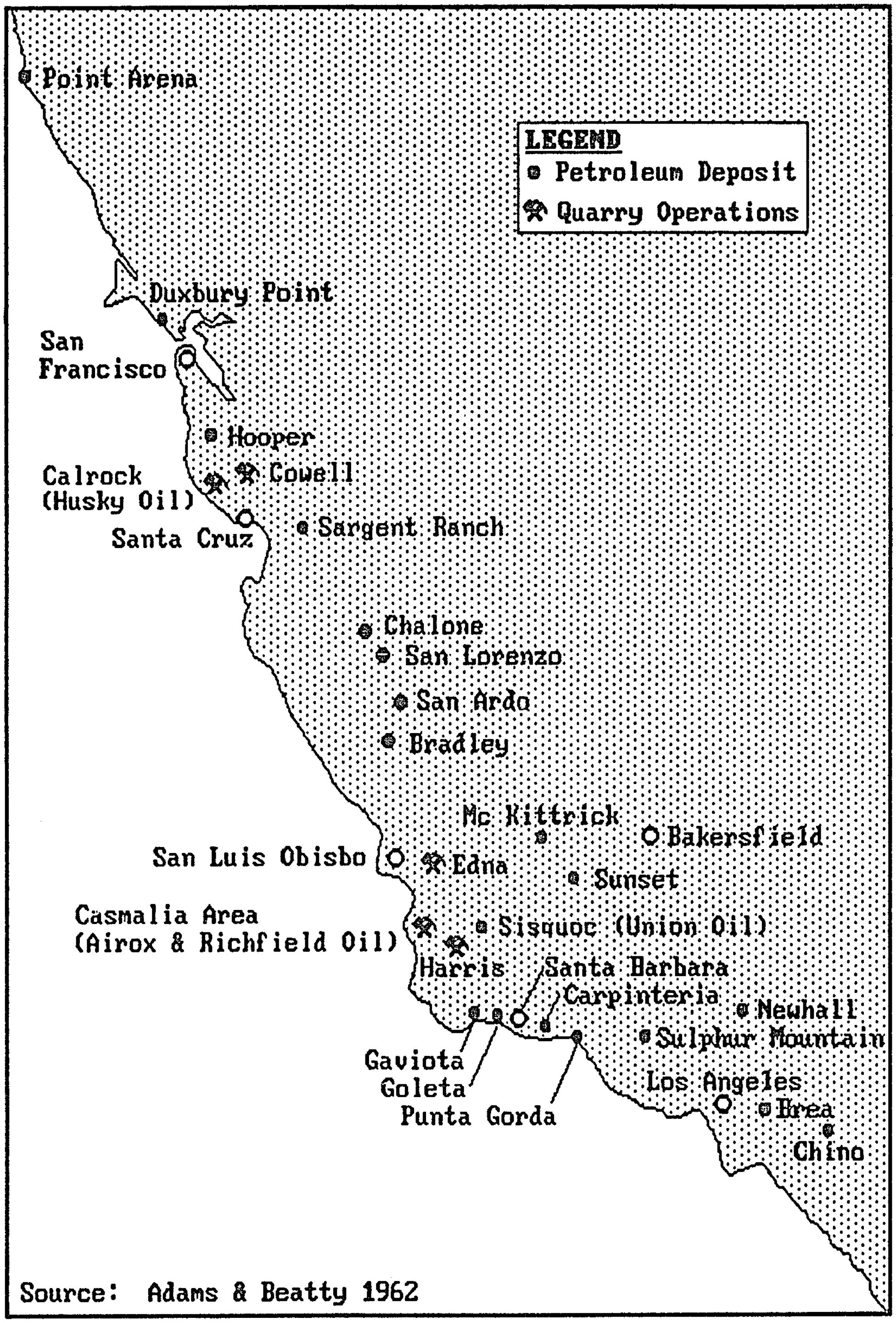


Figure 14. Petroleum reserves in close association with Monterey Group Formations located within Central California's Coast Range.

By applying the information learned about MB Cherts depositional environment, geologic age, and the tectonic forces that created it, large portions of the study area were eliminated from the survey. By overlaying maps of specific geologic features, only those areas with high potentials for producing MB Chert were actually surveyed. However, this does not mean that MB Chert does not occur in other areas or outside of the current study area; it most likely does.

CHAPTER III: TECHNIQUES USED TO ANALYZE MONTEREY BANDED CHERT

Introduction

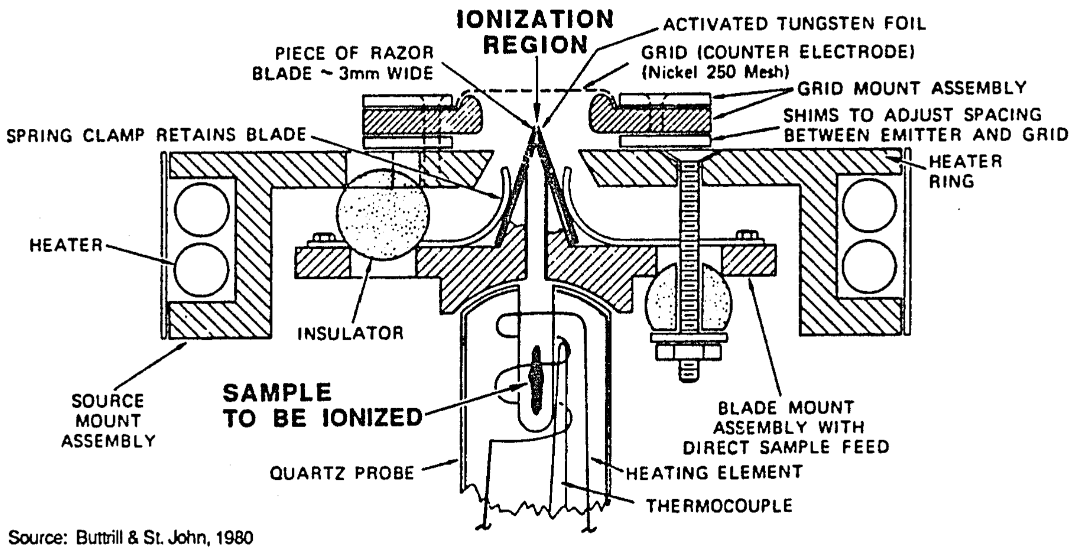
Trace element analysis has not been successful in this and other studies for sourcing artifacts manufactured from Monterey Banded (MB) Chert. Therefore, other means of identification were employed in this research project. Most analytical techniques used in this study consisted of nondestructive testing, except x-ray powder diffractometry, thermogravimetric analysis, and field ionization mass spectrometry. The nondestructive tests included: scanning electron microscopy, energy dispersive x-ray, and x-ray diffractometry. The following describes these techniques that are commonly used in the fields of materials research and geophysics.

Field Ionization Mass Spectrometry

Field Ionization Mass Spectrometry (FIMS) is a relatively new technique used in materials research, petroleum research, and oil exploration. In a short time, FIMS has become an essential tool within the petroleum industry. It is used for determining discreet hydrocarbon identities (fingerprints) of petroleum resources, their derivatives, and by-products. In industry, this technique has been used by the U.S. Coast Guard for establishing responsibility for oil spills within United States waters.

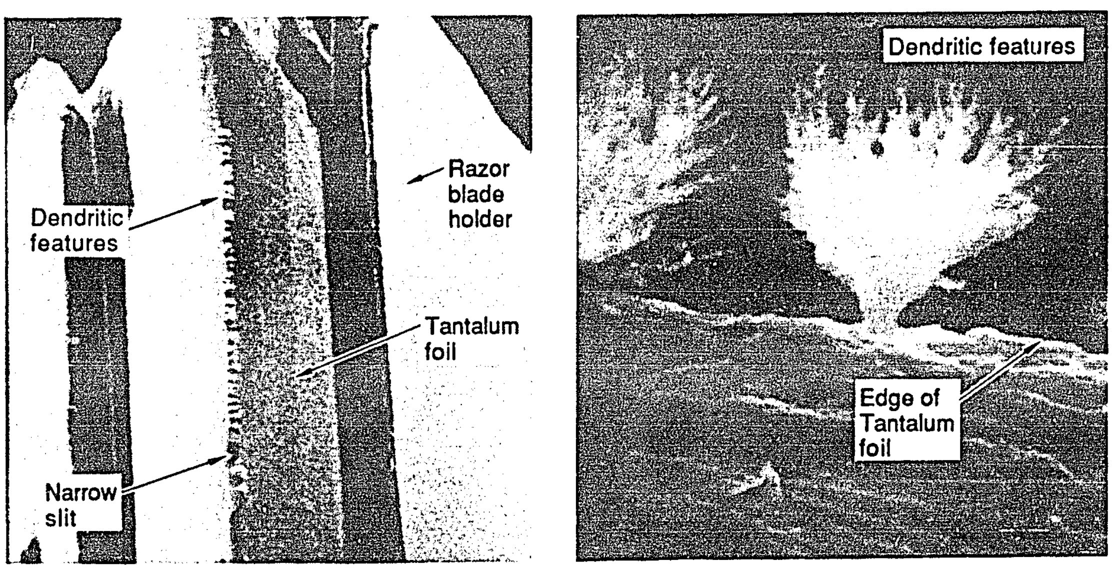
Although FIMS is a destructive process of analysis, it has the ability to analyze the complete hydrocarbon (organic) content of lithic materials. In addition to printouts of raw data (Figure 1), FIMS also graphs its own results in histogram form (Figure 2). A 20 mg lithic sample is all that is required for FIMS analysis, about the same amount needed for an obsidian hydration analysis. Of all techniques used in mass spectrometry, FIMS has the unique ability to produce unfragmented molecular ions from any organic compound. Because of the nonfragmentary nature of FIMS, analysis of complex mixtures and identification of the homologous series of hydrocarbons (petroleum) is now possible.

Ionization occurs when gaseous molecules of organic samples pass through a narrow slit of intense electric field (Figure 15). Under these conditions, an electron tunnels from the organic molecule to the field emitter, producing a molecular ion. To produce the necessary field strengths required for ionization of the chert samples, many extremely small pointed emitters were required (Figure 16). Mass spectrographic analysis is then performed by conventional magnetic sector techniques (Figure 17). FIMS spectra of fossil fuels, such as petroleum, show characteristic patterns that repeat every 14 atomic mass units (amu) (Buttrill and St. John 1980).



Source: Buttrill & St. John, 1980

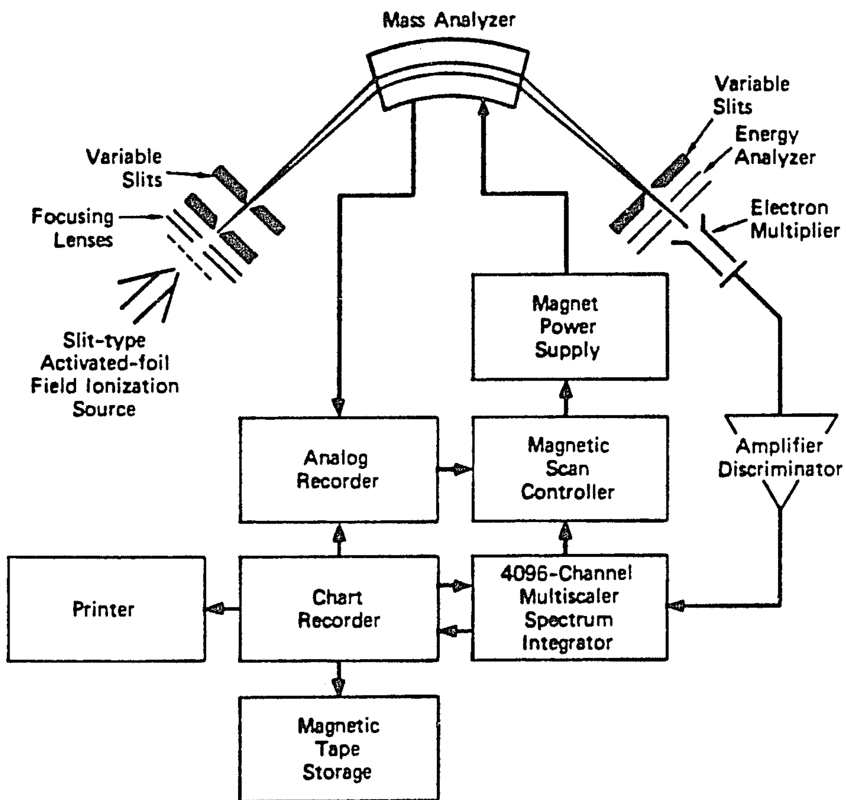
Figure 15. Exploded view of the slit-type preactivated Tantalum foil ionization source and its head assembly within the FIMS.



(a) Ionization region.

(b) Increased surface area.

Figure 16. Slit-type preactivated Tantalum foil ionization source for the FIMS and its dendritic features.



Source: Buttrill & St. John, 1980

Figure 17. Flow diagram of the mass spectrometric system utilized for the FIMS analyses.

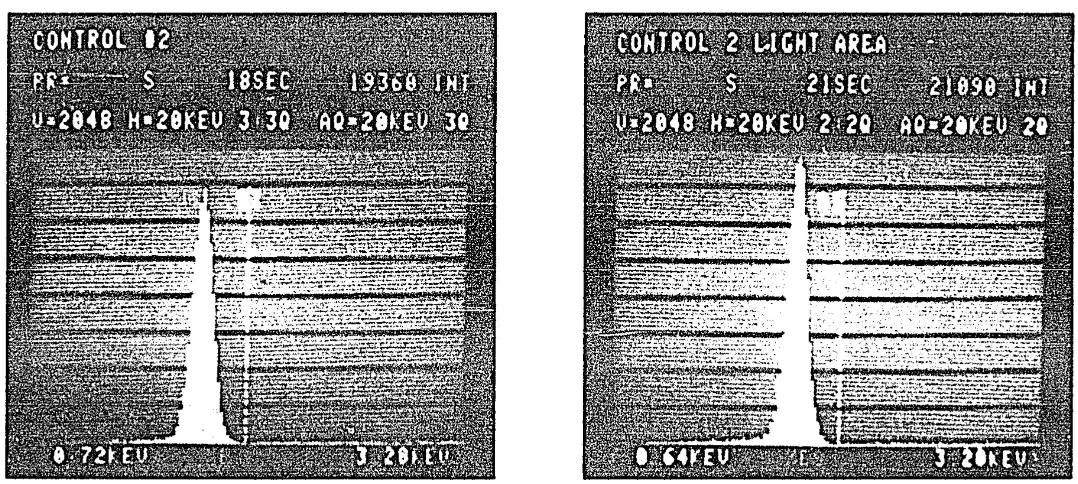
Geologic specimens of MB Chert are prepared for FIMS analysis in much the same manner as those prepared for x-ray powder diffractometry (XRPD). Because FIMS analyzes organic compounds, contamination is a serious problem. Therefore, a few additional steps in the sample preparation are necessary to circumvent contamination. Analytical samples were removed from the interior of chert cobbles by using clean lapidary tools. This technique was used to reduce or eliminate surface contamination in the samples tested. Care was also taken not to touch the chert samples, since fingerprints would also introduce foreign hydrocarbons into the sample, thus contaminating them.

Only a 20 mg sample was required for each FIMS analysis. Initially, two samples from each specimen were prepared separately and analyzed at different times. This guaranteed consistency of sample preparation, equipment, and techniques used. However, uniformity of test results are not guaranteed because MB Chert and other lithic materials were not homogeneous. It was anticipated that test results would be similar but not identical because of the nonhomogeneous nature of MB Chert.

Many hydrocarbon peaks were displayed within the FIMS graph (Figure 2). The identity of any particular set of peaks was not as important as establishing the fact they existed and exhibited unique patterns. Numbers in the printout (Figure 1) represent ion counts, while numbers on the graph represent relative percentages of atomic mass units. The only set of spectral peaks that identify a sample as MB Chert are the petroleum biomarkers located between 470-560 amu. The balance of the histogram represents the total hydrocarbon (organic) content found within the sample.

Energy Dispersive X-Ray

Energy dispersive x-ray (EDX) is a nondestructive analysis similar to x-ray fluorescence, except that it measures x-rays directly. Measurements are taken directly from the samples, and the recorded energies from the various emission lines increase monotonically with their atomic number. Therefore, spectral peaks become extremely simple to identify with their corresponding elements (Russ 1972). Preparation of chert specimens for EDX analysis was similar to SEM sample preparation, except that specimens were not sputter-coated. This would have introduced foreign elements (gold palladium) into the chert samples. The following was a typical example of an EDX trace element analysis (Figure 18).



(a) Black Monterey Banded Cherts

(b) White Monterey Banded Cherts

Figure 18. Typical energy dispersive x-ray analysis of Monterey Banded Chert samples.

Scanning Electron Microscopy

Scanning electron microscopy (SEM) is a versatile, nondestructive, and widely used analytical tool of modern science. A well-established research tool for surface studies, SEM has high resolution approaching 65 Å (0.0065 mm) (Nester 1983; Postek et al. 1980). Preparation of the chert specimens for examination under the SEM involved detailed procedures necessary to protect the SEM's column, apertures, and filament from contamination. The preparation steps were:

- Inert gas was used to blow away any loose or foreign debris from the sample;
- Chert samples were initially sonic-cleaned in distilled water to remove any loose or foreign debris;
- The samples were again sonic-cleaned in anhydrous ethanol to remove any surface moisture;
- The samples were finally sonic-cleaned in a reagent grade acetone to remove any oily substances from the porous surface;
- Chert samples were mounted on a conductive SEM specimen stub;
- Conductive silver (colloidal) paint was applied around at least three edges of the sample. The conductive paint was to drain off any excess charge built up by the electron beam of the SEM;
- The chert samples were allowed to air dry in a vacuum desiccator;
- Samples were again blown with an inert gas to remove any accumulated dust before sputter coating; and
- Then the chert specimens were sputter coated.

This lengthy procedure was required to prepare each MB Chert specimen for examination under the SEM (Figure 19).

Figure 19. Typical scanning electron microscopy micrograph of a Monterey Banded Chert flake recovered from an archaeological site.

<u>Thermogravimetric Analysis</u>

Thermogravimetric analysis (TGA) is a destructive technique. TGA was used to discover which volatile materials, incorporated within MB Chert, were responsible for its low thermal tolerance and explosive nature. This test determined what percentage of MB Chert was absorbed moisture, chemically combined water, volatilized hydrocarbons, and inorganics. Preparation of lithic samples for TGA analysis was identical to the FIMS procedures. Sample weights (20 mg) and thermal ranges were continuously monitored by a strip-chart recorder (Figure 20).

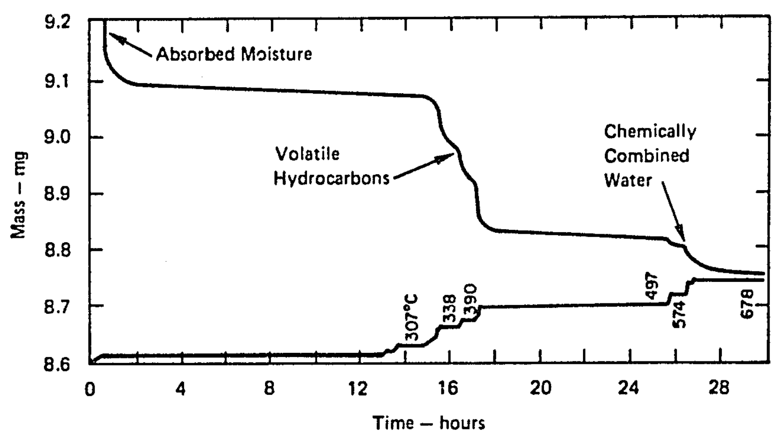


Figure 20. Typical thermogravimetric recording of a Monterey Banded Chert specimen.

X-ray Powder Diffractometry

X-ray diffractometry (XRD) can be a nondestructive analysis of a mineral's molecular structure. However, x-ray powder diffractometry (XRPD) produces a more acceptable result, but is a destructive process. In this study, XRPD was used to examine both artifactual and geologic samples of MB Chert for trace minerals and possible thermal effects. XRPD is used to detect minute differences between interplanar distances within crystalline structures for positive mineral identification. Since every known crystalline substance produces unique diffraction patterns (fingerprint), the study of diffraction patterns offers a qualitative analysis for positive mineral identification. By comparing traces obtained from MB Chert specimens with known standards, specific mineral identification can be established. Extensive preparation was necessary to obtain consistent results from each lithic sample. Before testing geologic or archaeological specimens, known standards were run to calibrate the equipment and create standards for later comparison (Figure 21). An α-quartz standard and a known chert specimen were the first analyzed.

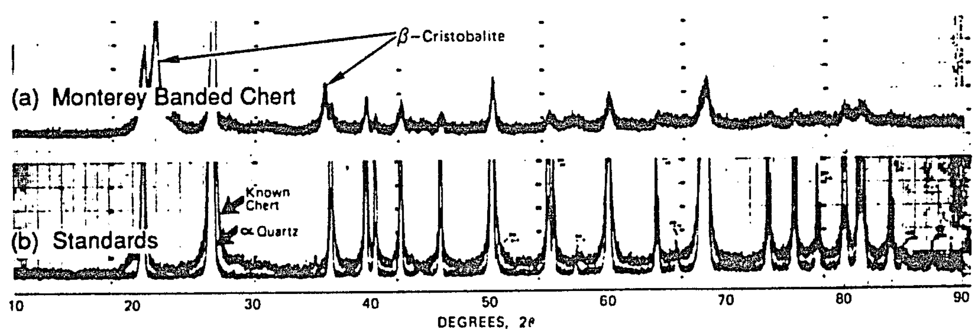


Figure 21. Typical x-ray powder diffractograms of two known hydrosilicate standards (chert and quartz).

Crystallinity Index

The crystallinity index (CI) of hydrosilicates is based on the relative degree of resolution at reflection peak #212 between 66-69° 2θ (Figure 22). Most hydrosilicates exhibit a maximum resolution at these reflection angles. The computed measurements were adjusted for a relative index between 1-10 (Figure 23). The CI of 10 was reserved for an ideal sample of optically clear Herkimer Quartz (Figure 24). CI is a function of the internal crystalline groundmass, but may also be affected by internal distortions induced by stress. Care must be taken when measuring CI to exclude any area with obvious crystalline abnormalities within the groundmass. The formula for computing CI from the relative intensity of peak #212 at 67.74° is CI = (10aF/b). Where "a" is the intensity (relative height) of peak #212 from the next trough, "b" is the total intensity (relative height) of peak #212 from the base line, and "F" is the unique correction (calibration) factor for a particular piece of equipment (Murata and Norman 1976).

Among hydrosilicates analyzed by Murata and Norman, profiles range from a simple broad hump (CI=<1.0) through a series of profiles (Figure 23). Resolution evolved into sharp well-defined profiles with increased CI. Hydrosilicates with a CI of <1.0 cannot be calculated as 0, since quartz always produces a strong XRD pattern (Murata and Norman 1976).

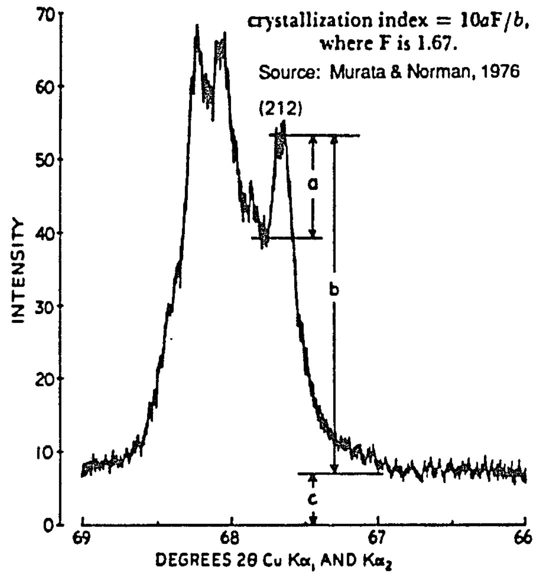


Figure 22. Typical x-ray powder diffractogram (peak #212) of a well-crystallized quartz standard.

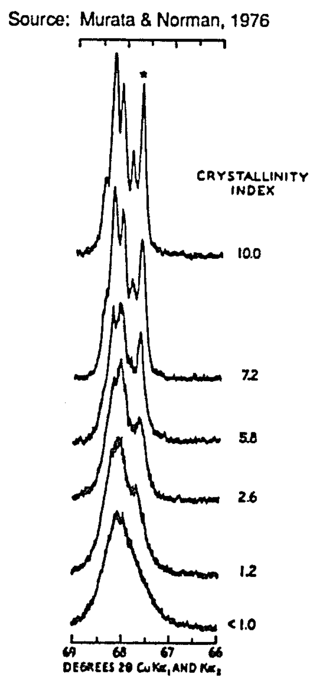


Figure 23. Example of the increasing order of crystallinity.

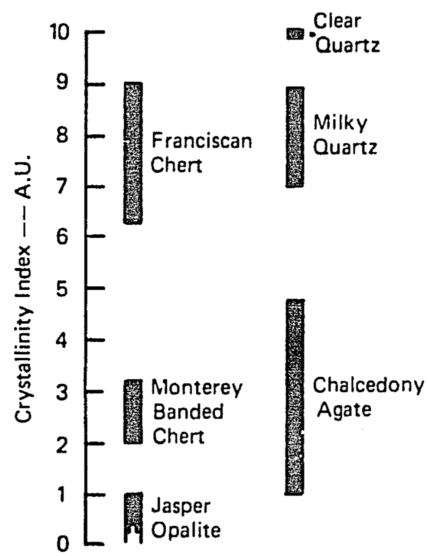


Figure 24. Crystallinity Index and its hydrosilicate counterpart.

CHAPTER IV: MONTEREY BANDED CHERT, A SOURCE OF LITHIC ARTIFACTS

The majority of knappable rocks within Central California are composed of many varieties of hydrosilicates. To even begin to separate the diverse varieties would be a monumental task. Therefore, a systematic process of segregation needed to be included into the fingerprinting process (Figure 22). To impose reasonable limits upon the scope of this research project, only the black (dark brown) varieties of MB Chert are addressed. After sorting collections for different types of black lithic materials, the hydrosilicates were sorted as follows:

- Hydrosilicates were initially segregated by color. Lithic samples not falling into the black category were eliminated.
- Black hydrosilicates were analyzed with scanning electron microscopy to determine whether they were microcrystalline or cryptocrystalline. MB Cherts were cryptocrystalline; any materials with a microcrystalline groundmass were removed.
- The remaining lithic materials were then analyzed with energy dispersive x-ray to establish their elemental content. True MB Chert contains only silica, samples containing other trace elements were reclassified as Monterey Group Chert and set aside for further analysis.
- Opaque samples were also placed into the Monterey Group category for further study, since most MB Cherts were translucent.

- The residual lithic materials were considered to be MB Chert and were candidates for further examination under field ionization mass spectrometry (FIMS).

FIMS will determine from what general geologic source area the specimen originated. The additional analyses also discovered that many heat-treated specimens exhibited slightly different fingerprints from their parent materials. Therefore, the process of thermal alteration was examined as part of this study (Parsons 1987).

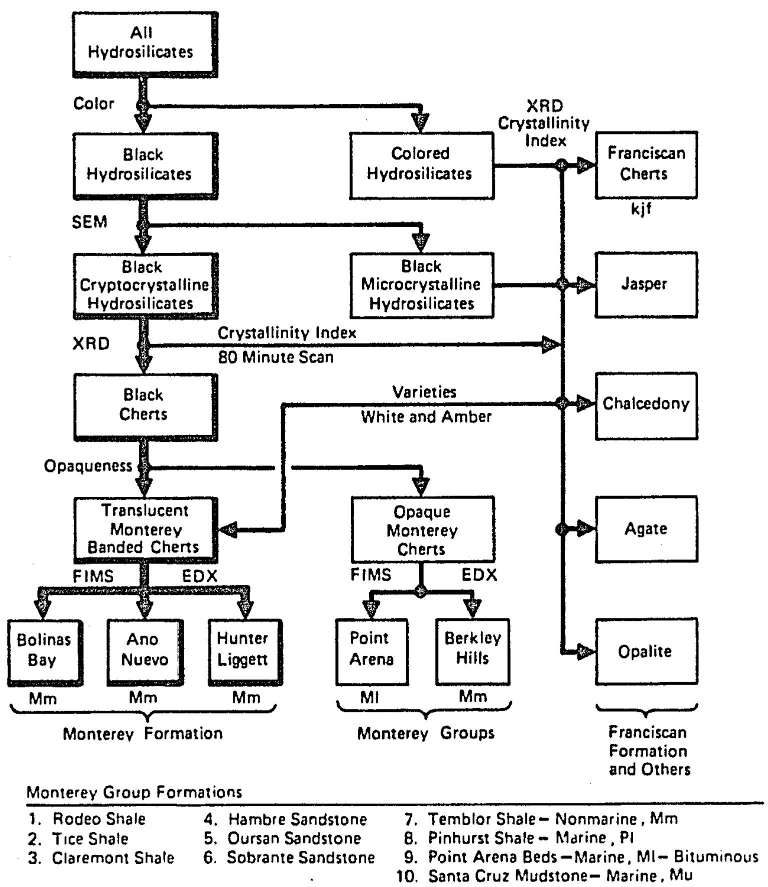
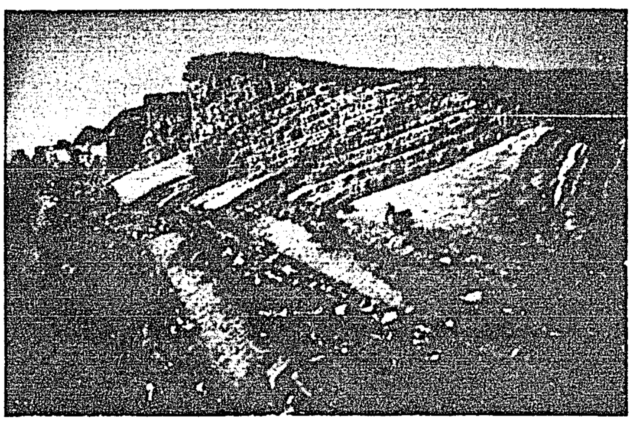


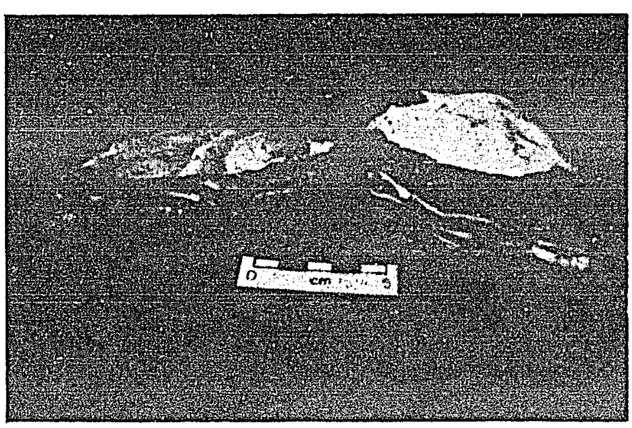
Figure 25. Flow diagram indicating the procedures for identifying hydrosilicates from Central California's Coastal Range.

Physical Description

Monterey Banded (MB) Chert and the Monterey Shale Formation were named after the city and county where their geologic type locality was established near Monterey, California (Galliher 1930). The majority of MB Chert found in Central California is typically dark brown (almost black), translucent, and distinctively banded (Figure 26). MB Chert also exhibits a high luster, vitreous appearance, has specific gravities between 2.0-2.65, and a relative Mohs' hardness between 7.0-7.5 (Dana and Dana 1952).



(a) Typical Monterey Shale Formation shown here at Ano Nuevo Point, San Mateo County.



(b) Typical Monterey Banded Chert from Ano Nuevo Point, San Mateo County.

Figure 26. Example of the steeply dipping Monterey Shale Formation and its unique Monterey Banded Chert.

While similarities exist, MB Chert is extremely versatile and occurs in many patterns of banding, degrees of opaqueness, and a variety of colors. Common varieties range from very dark brown to stark white. The most common combinations are:

- Dark brown (Munsell 10YR, 2/1), semitranslucent, and well-banded with light gray (Munsell 10YR, 7/1) bands;
- Chocolate brown (Munsell 10YR, 6/2), opaque, and well-banded with tan (Munsell 10YR, 8/2) bands;
- Amber (Munsell 10YR, 4/3), semitranslucent, well-banded with white (Munsell 10YR, 8/0) diatomaceous material, and cream (Munsell 10YR, 8/1) inclusions; and
- White (Munsell 10YR, 8/1), opaque, and well-banded with white (Munsell 2.5Y, 8/0) semitranslucent bands.

Along the Central California Coast, the predominant varieties of MB Chert are dark brown, semitranslucent, and well-banded. Chocolate brown, opaque, and well-banded varieties are the second most abundant form and the amber, well-banded, translucent varieties are the third most prevalent form. However, after further analysis, amber varieties proved to be MB Chalcedony, not MB Chert. White, near white, and gray varieties of MB Chert are the third most prevalent forms in Central California. Occasionally, MB Chert occurs with small patches of red or yellow. When true MB Chert is freshly broken, it produces a distinct odor of crude petroleum, and when overheated, it produces a pungent odor of burnt tires.

Many lithic materials within Central California's coastal range are mistaken for MB Chert. These were also examined during this study for a proper segregation to be made (Parsons 1986a). Extensive thermal maturation studies have been used to divide most sedimentary rocks into three kerogen categories, based on their hydrocarbon content, as follows:

- Type I kerogen was derived entirely (100%) from marine organisms;
- Type II kerogen was derived from equal amounts (50/50%) of both marine and terrestrial detrital materials; and
- Type III kerogen was derived entirely (100%) from terrestrial sources (Philp 1986).

Extensive SEM examination of 348 MB Chert samples discovered that nearly all of the MB Chert was of the type II kerogen category, which suggested a near terrestrial association.

Geologic Sources of MB Chert and Their Fingerprints

After countless exploratory trips into the field and expenditure of hundreds of hours, only two major and four minor geologic sources of true MB Chert were discovered. In addition to these, five geologic source areas of MG Chert and two pseudo varieties were also located (Table 1). The term Monterey Group (MG) Chert is used to encompass all other cherts originating from any MG Formation. The Monterey Shale Formation that produces true MB Chert, is one of the largest and most important members of this group.

Table 1
Sources of Black Hydrosilicates
in Central California's Coast Range

A. True MB Chert sources are (from north to south);

1. The first minor source area is located on the south side of **Point Arena**. The chert occurs as small, very dark brown, translucent, and poorly banded beach pebbles (float), cobbles are rare.

2. The second minor source area is located at the southern end of **Schooner Gulch**. The chert occurs as small, very dark brown, translucent, and poorly banded beach pebbles (float), cobbles are rare.

3. The third minor source area is located on the west side of **Bolinas Point**. The chert occurs in the form of fist size cobbles, very dark brown, almost translucent, and poorly banded talus blocks (float), beach pebbles are rare.

4. The first major and prolific source area is located on **Punta del Año Nuevo**. The chert occurs as predominantly dark or light brown, well banded beach boulders on northern beaches, cobbles on most beaches, and pebbles on the southern beaches (float).

5. The fourth minor source area is located within the Santa Cruz Mudstone Formation that is exposed in the sea-cliff near **Big Creek**. The chert occurs as very dark brown, well banded, translucent, and well rounded beach pebbles weathering out of the formation (in situ, secondary deposition).

6. The second major and largest geologic source area is located on the **Hunter Liggett Military Reservation**. The chert occurs as stream pebbles and cobbles within most stream beds, as talus boulders along hillsides, and in situ within the Monterey Shale Formation. The chert is predominantly dark brown, translucent, and well banded, but also occurs as massive blocks in amber, chocolate brown, white, and near black.

Table 1
(Concluded)

<u>B. Other MG Chert and pseudo sources are (north to south);</u>

1. A moderate source of MG Chert is located on the beaches of **Point Arena Cove**. The chert occurs as float, very dark brown, opaque, and unbanded beach cobbles or pebbles.

2. A small source of MG Chert is located on the beaches of **Schooner Gulch Cove**. The chert occurs as float, very dark brown, opaque, and unbanded beach cobbles or pebbles.

3. A small source of MG Chert can be found on the western side of **San Pablo Reservoir**. The chert occurs as talus, very dark brown, opaque, and unbanded talus cobbles or pebbles.

4. A moderate geologic source of MG Chert can be found within the Berkeley Hills, above **Canyon City**, and within the Claremont Formation. The chert occurs <u>in situ</u> as very dark brown, opaque, and unbanded lenses and plates.

5. Another moderate source of MG Chert can be found in the headwaters of **San Lorenzo Creek**, within the town of Canyon City. The chert occurs as float, very dark brown, opaque, and unbanded stream cobbles and pebbles.

6. Their is an excellent pseudo variety (e.g., black translucent, and faintly banded Franciscan Chalcedony) originating from an <u>in situ</u> source south of San Jose, near the town of **Coyote**.

7. A pseudo source was located near **San Ardo** as talus in many roadcuts. The material is in reality a translucent amber chalcedony.

8. Many isolated pseudo varieties (e.g., amber MB Chalcedony and sard) are found within the **Hunter Liggett** source area.

Every source of MB Chert located was recorded, mapped, photographed, and lithic samples collected for later analysis.

Because three geologic sources of MG Chert (Año Nuevo #A1, Hunter Liggett #H3, and Schooner Gulch) exhibited similar histogram patterns, further breakdown of the field ionization mass spectrometry (FIMS) data was required for proper segregation. The FIMS data had to be replotted three-dimensionally into thermal ranges for the proper distinctions to be made.

Punta del Año Nuevo. Año Nuevo sources are located on the southern San Mateo coast, 44 miles southeast of the Golden Gate Bridge toll plaza, and 22 miles northwest of the Santa Cruz City Limits. Good quality MB Chert can be found at several locations on and around Año Nuevo Point. The analysis of six geologic samples of MB Chert from as many sources in the Año Nuevo Point area, revealed nearly identical fingerprints.

The only in situ geologic occurrence of MB Chert found at Año Nuevo was a cobble conglomerate (secondary deposition) outcrop on the north side of the north point, within the Purisima Formation. All other Año Nuevo sources were reworked float deposits that were not in situ. At this location, the Purisima Formation forms a small marine terrace that projects a quarter mile into the ocean. Hypothetically, this may be the only remnant of a much larger outcropping of cobble conglomerates that once existed here. Geologists do not agree, but most theorize the ocean had long since eroded away the major portion of this outcropping. Then ocean waves and the down-shore current redeposited the debris in a southerly direction, along Año Nuevo's beaches.

Proof of this redeposition process was that no natural geologic source could be discovered that would explain the copious amounts of MB Chert present on the beaches. The down-shore current would have transported the chert south along Año Nuevo's beaches, wearing it down in the process. Also, no naturally occurring MB Chert was located north of the cobble conglomerate outcropping. Lithic materials, as they traveled southward by the down-shore current, were ground down by the erosive action of ocean waves on sandy beaches (Tarbuck and Lutgens 1984). Año Nuevo is an exemplary example of this erosive process that can be demonstrated by the following:

- Immediately south of the cobble conglomerate outcropping, numerous MB Chert cobbles and boulders are evident, high up on the beaches.
- A short distance to the south, between the north and south points, the relative size of MB Chert cobbles are smaller and the distribution is less abundant.
- On the southern beaches, MB Chert is not only more difficult to find, but has been reduced to pebble size.
- Even farther south, below Año Nuevo Creek and north of Waddell Creek, MB Chert is scarce and has been reduced to gravel-size.

Año Nuevo locality A1 (#A04401), is a major source of MB Chert, exposed along the northern beaches of the north point. The chert is found as medium-to-large cobbles, boulders, and plates scattered on the beach. Northwesterly prevailing winds continually blow sand off the northern beaches onto the marine terrace, leaving MB Chert exposed all year long. This easy availability made it a prime collecting area for the prehistoric inhabitants, as indicated by the many lithic manufacturing sites immediately adjacent to this source (Parsons 1982). Analyses of the chert from Año Nuevo locality A1 revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and isolated pockets of free colloids;
- CI of 1.3 indicated this material was a MB Chert;
- EDX disclosed a pure silica content; and
- FIMS displayed a typical Año Nuevo wedge pattern with petroleum biomarkers around 500 amu (Figure 27).

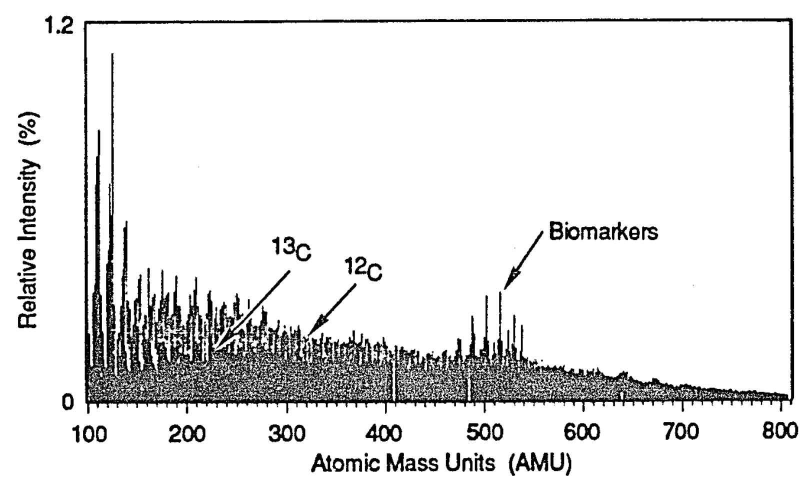


Figure 27. FIMS analysis (#A04401) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Año Nuevo locality A1.

Table 2
Monterey Banded Chert and Pseudo Materials from Central California

No.	Location	Color		SEM	CI	EDX	FIMS	Material
01	Año Nuevo	A1	black	crypto	1.3	Si	yes	MB Chert
02	"	A2	black	crypto	0.7	Si	yes	MB Chert
03	"	A3	black	crypto	-	Si	yes	MB Chert
04	"	A4	black	crypto	0.9	Si	no	MB Chert
05	"	A5	black	crypto	-	Si	no	MB Chert
08	"	A6	red	crypto	3.5	Si	yes	RC Jasp.
07	Bird Point	1	black	crypto	-	Si	yes	MB Chert
08	Black Point	1	black	micro	-	trace	no	BF Chert
09	Bodega Head	1	black	micro	-	trace	no	BF Chert
10	Bolinas Point	1	black	crypto	-	Si	yes	MB Chert
11	"	2	black	crypto	-	Si	no	MB Chert
12	Canyon City	C1	black	micro	-	trace	no	MG Chert
13	"	C2	black	micro	-	trace	yes	MG Chert
14	"	C3	black	micro	-	trace	no	MG Chert
15	"	C4	black	micro	-	trace	no	MG Chert
16	"	C5	black	crypto	-	trace	no	MG Chert
17	"	C6	black	crypto	-	trace	no	MG Chert
18	"	C7	black	crypto	-	trace	no	MG Chert
19	Columbia	1	black	crypto	1.4	trace	yes	SB Chal.
20	"	2	black	crypto	-	trace	no	SB Chal.
21	"	3	black	crypto	-	trace	no	SB Chal.
22	Coyote	1	black	crypto	1.6	Si	yes	BF Chal.
23	"	2	black	micro	-	trace	no	BF Chert
24	"	3	red	micro	-	trace	no	RF Chert
25	"	4	green	micro	-	trace	no	GF Chert
26	"	5	white	micro	-	trace	no	WF Chert
27	"	6	brown	micro	-	trace	no	BF Chert
28	Coyote Hills	1	red	micro	8.8	trace	yes	RF Chert
29	"	2	red	micro	-	trace	no	RF Chert
30	Dos Rios	1	black	micro	-	trace	no	BF Chert
31	"	2	black	micro	-	trace	no	BF Chert
32	False Sur	1	black	micro	-	trace	no	BF Chert
33	"	2	black	micro	-	trace	no	BF Chert
34	Fort Cronkite	1	black	micro	-	trace	no	BF Chert
35	Fort Baker	1	black	micro	-	trace	no	BF Chert

Table 2
(Continued)

No.	Location	Color		SEM	CI	EDX	FIMS	Material
36	Fort Bragg	1	black	micro	9.5	trace	yes	BF Chert
37	"	2	black	micro	-	trace	no	BF Chert
38	"	3	black	micro	-	trace	no	BF Chert
39	"	4	black	micro	-	trace	no	BF Chert
40	Fort Ross	1	black	micro	-	trace	no	BF Chert
41	"	2	black	micro	-	trace	no	BF Chert
42	Golden Gate	1	red	micro	-	trace	no	RF Chert
43	"	2	red	micro	-	trace	no	RF Chert
44	Halls Valley	1	red	micro	-	trace	no	RF Chert
45	"	2	green	micro	9.2	trace	yes	GF Chert
46	Laurel Hill	1	red	micro	-	trace	no	RF Chert
47	"	2	green	micro	-	trace	no	GF Chert
48	Navaro River	1	black	micro	-	trace	no	BF Chert
49	"	2	black	micro	-	trace	no	BF Chert
50	"	3	black	micro	-	trace	no	BF Chert
51	"	4	black	micro	-	trace	no	BF Chert
52	Mission Creek	H1	black	crypto	-	Si	yes	MB Chert
53	"	H2	black	crypto	-	Si	yes	MB Chert
54	"	H3	black	crypto	-	Si	yes	MB Chert
55	Muir Beach	1	black	micro	-	trace	no	BF Chert
56	Point Arena	1	black	crypto	-	Si	yes	MG Chert
57	"	2	black	crypto	-	Si	yes	MG Chert
58	"	3	black	crypto	-	Si	no	MG Chert
59	"	4	black	crypto	-	Si	no	MG Chert
60	Point Reyes	1	black	micro	-	trace	no	BF Chert
61	"	2	black	micro	-	trace	no	BF Chert
62	Russian Gulch	1	black	micro	-	trace	no	BF Chert
63	San Antonio R.	H5	black	crypto	-	Si	no	MB Chert
64	"	H6	amber	crypto	-	Si	no	MB Chal.
65	"	H7	black	crypto	-	Si	no	MB Chert
66	"	H8	brown	crypto	-	Si	no	MB Chert
67	"	H9	amber	crypto	-	Si	no	MB Chert
68	"	H10	gray	crypto	-	Si	no	MB Chert
69	"	H11	white	crypto	-	Si	no	MB Chert
70	"	H12	yellow	crypto	-	Si	no	MB Chert

Table 2
(Concluded)

No.	Location	Color		SEM	CI	EDX	FIMS	Material
71	"	H13	red	crypto	-	Si	no	MB Chert
72	San Ardo	1	milky	crypto	-	Si	yes	?? Chal.
73	San Pablo Dam	1	black	micro	-	trace	yes	MG Chert
74	Schooner Gulch	1	black	crypto	-	Si	yes	MG Chert
75	"	2	black	crypto	-	Si	yes	MG Chert
76	"	3	black	micro	-	trace	no	MG Chert
77	Sea Ranch	1	black	micro	-	trace	no	BF Chert
78	"	2	black	micro	-	trace	no	BF Chert
79	Sulfur Springs	H4	black	crypto	-	Si	no	MB Chert
80	"	H14	black	crypto	-	Si	no	MB Chert
81	"	H15	amber	crypto	-	Si	no	MB Chert
82	"	H16	brown	crypto	-	Si	no	MB Chert
83	"	H17	gray	crypto	-	Si	no	MB Chert
84	Tomalas Bay	1	black	micro	-	trace	no	BF Chert
85	"	2	black	micro	-	trace	no	BF Cher
86	"	3	black	micro	-	trace	no	BF Chert
87	"	4	black	micro	-	trace	no	BF Chert

micro = Microcrystalline
crypto = Cryptocrystalline
chal. = Chalcedony
trace = Trace elements present
Si = Only pure silica present
?? = Unknown material
Jasp. = Jasper
R. = River

MB = Monterey Banded
MG = Monterey Group
SB = Sierran black
BF = Black Franciscan
GF = Green Franciscan
RF = Red Franciscan
RC = Red coastal

Año Nuevo locality A2 (#A04402) is centrally located between Año Nuevo's north and south points. MB Chert cobbles found at this locality are good quality, fist-sized, and in moderate abundance. The relative abundance and availability of this material is seasonal, similar to southern beach sources. The seasonality of this chert source depends upon winter storms, their resulting wave patterns, currents, and prevailing winds. Analyses of chert from the Año Nuevo locality A2 revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- CI of 0.7 indicated this material was a MB Chert;
- EDX disclosed a pure silica content; and
- FIMS displayed a typical Año Nuevo wedge pattern with the petroleum biomarkers around 500 amu (Figure 28).

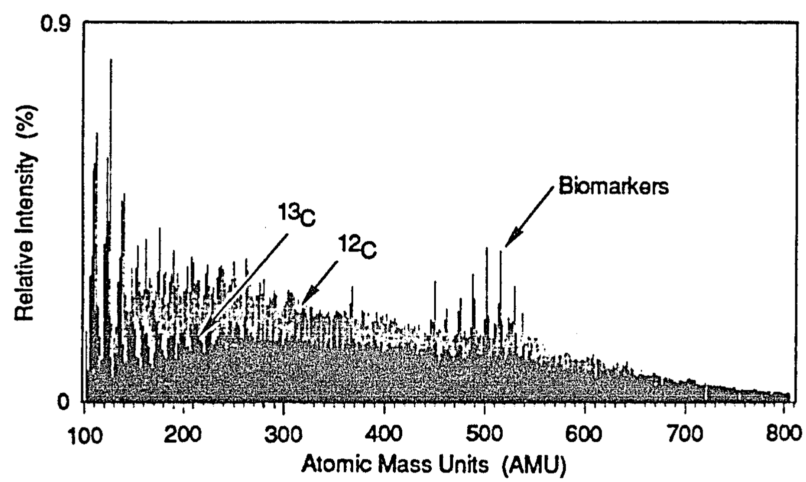


Figure 28. FIMS analysis (#A04402) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Año Nuevo locality A2.

Año Nuevo locality A3 (#A04403) produced MB Chert in relatively minor amounts along the southern beaches of south point. Here, the chert occurs as pebbles with occasional cobbles and plates among the seasonally exposed beach gravels. The Pacific Ocean's winter wave system and down-shore current relocates tremendous amounts of sand onto off-shore bars. This seasonal action uncovers buried beach gravels, creates a series of berms high up on the beach, and exposes large amounts of MB Chert. Analyses of the chert from Año Nuevo locality A3 revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs, isolated pockets of free colloids, and bands of microcrystalline material (not typical);
- EDX disclosed pure silica; and
- FIMS displayed a typical Año Nuevo wedge pattern with petroleum biomarkers visible around 500 amu (Figure 29).

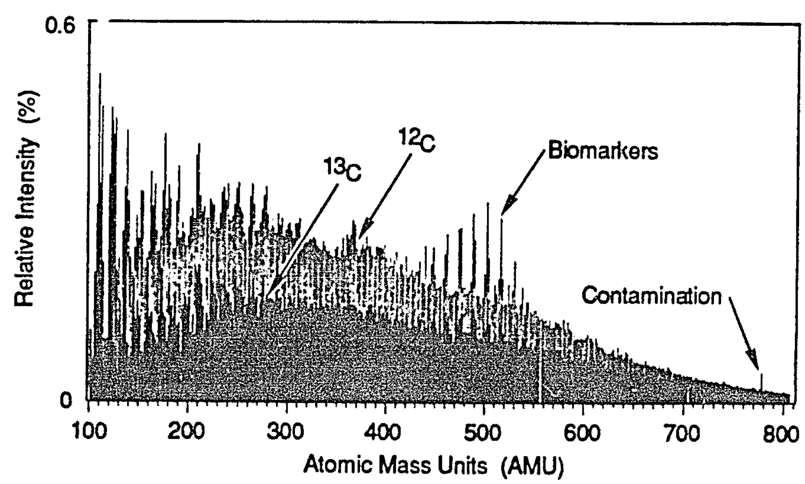
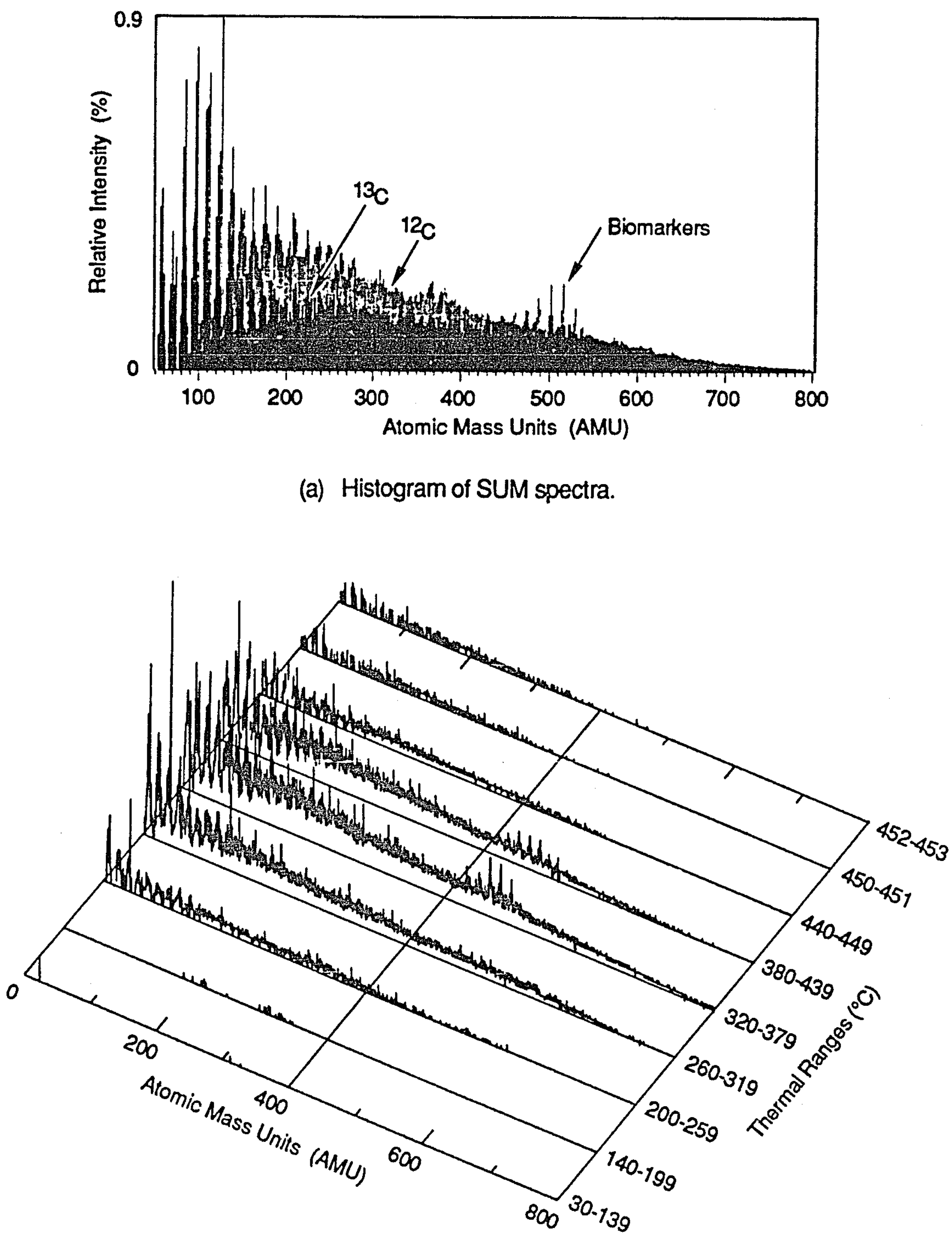


Figure 29. FIMS analysis (#A04403) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Año Nuevo locality A3.

Año Nuevo locality A4 (#A15902) may be the most important geologic source of all. Contained in situ within a marine terrace on the north side of the north point. The deposit is a meter thick cobble conglomerate that is imbedded within the upper portion of the Purisima Formation. The formation is in direct fault (Green Oaks Fault) contact with the Monterey Shale Formation, about a quarter mile to the southwest. The chert/andesite cobble conglomerate is situated one-meter below the formations nonconformable contact with a Pleistocene terrace deposit. The conglomerate was normally buried by sand during the entire year, but it is occasionally exposed by strong winter storm waves that remove enormous amounts of beach sand. The cobble conglomerate consisted entirely of MB Chert and andesite, a stone used prehistorically as hammerstones and choppers (Parsons 1986a). Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed pure silica;
- CI of 0.9 confirmed this material was a MB Chert; and
- FIMS displayed a typical Año Nuevo wedge pattern with petroleum biomarkers in the vicinity of 500 amu (Figure 30).



(a) Histogram of SUM spectra.

(b) Three-dimensional thermal separation of SUM spectra.

Figure 30. FIMS analysis (#A15902) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Año Nuevo locality A4.

Año Nuevo locality A5 is an extremely minor source of good quality MB Chert, located on the north side of the north point. The chert occurs as small isolated plates, embedded in situ within the Pliocene Purisima Formation. Analyses revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed pure silica; and
- No further analyses (FIMS) were performed on this material because of its proximity to other tested chert sources.

Año Nuevo locality A6 is another minor source of MB Chert and is located east of Año Nuevo State Beach, on the westerly-facing talus slopes of the Western Marine Terrace. The chert occurs as medium-sized plates (no cobbles) of MB Chert, randomly scattered on the surface with no evident origin. Many of the pieces show signs of intentional flaking and thermal alteration. This MB Chert appears to have been transported here by prehistoric inhabitants of the area and probably should be considered an archaeological site, rather than a geologic occurrence. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with a few vugs and pockets of free colloids;
- EDX disclosed pure silica; and
- No further analyses (FIMS) were performed on this material because of its questionable status and proximity to other tested sources of Año Nuevo MB Chert.

Big Creek. This locality (#A19601) is west of the coast highway, 47 miles southeast of the Golden Gate Bridge toll plaza and 18 miles northwest of the Santa Cruz City Limits. MB Chert found here occurs as small pebbles, cobbles, and plates weathering out of sea cliffs of the Santa Cruz Mudstone Formation. This is a secondary deposition of excellent quality MB Chert. The mudstone formation rests unconformably above the Monterey Shale Formation. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with occasional vugs and pockets of free colloidal material;
- EDX disclosed a pure silica content; and
- FIMS analysis produced a unique histogram pattern. Petroleum biomarkers were visible around 500 amu along with some contaminants around 770 amu (Figure 31).

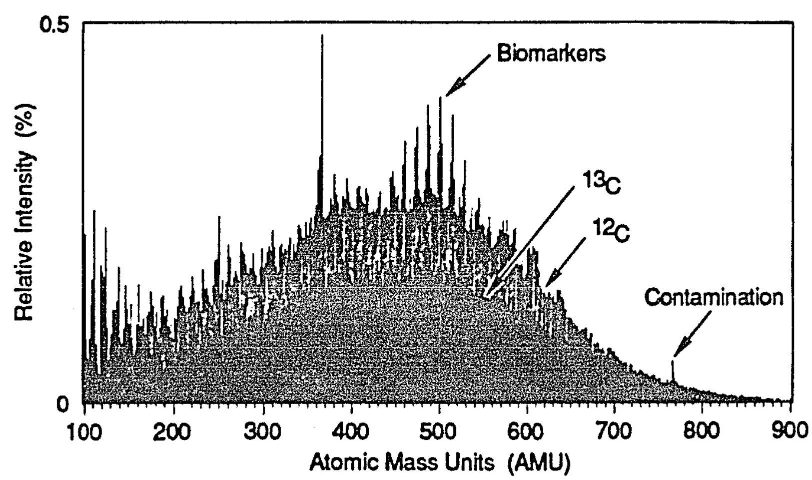


Figure 31. FIMS analysis (#A19601) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Big Creek locality.

Bolinas Point. This locality (#A02101) is on the coast, 17 miles northwest of the Golden Gate Bridge toll plaza and 15 miles southwest of Novato. The MB Chert is of poor quality and occurs as small cobbles on the beaches north of Duxbury Point. The Monterey Formation on the Point Reyes Headlands is in direct fault (San Andreas Fault) contact with the Franciscan Formation to the northeast. Even though this is cited as a Monterey Formation in many publications, it should possibly be called the Santa Cruz Mudstone Formation (Clark et al. 1984). Analyses of the chert revealed the following traits, typical of MB Chert
(Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed pure silica; and
- FIMS produced a unique histogram pattern. Petroleum biomarkers were visible through the massive hydrocarbon content around 500 amu (Figure 32).

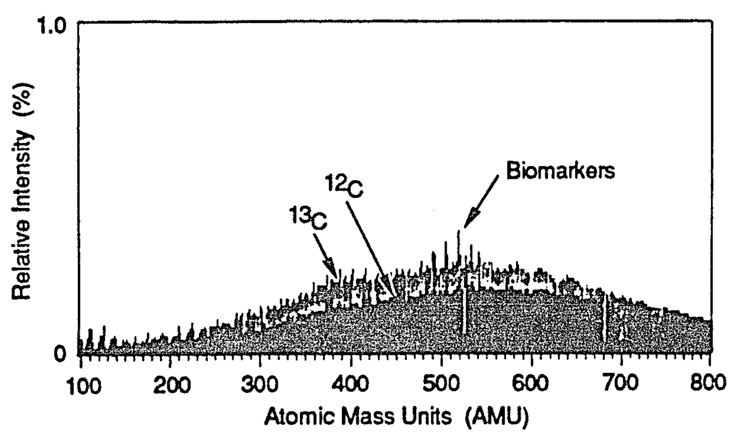


Figure 32. FIMS analysis (#A02101) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Bolinas point locality.

Canyon City. The Canyon City sources are located about 20 miles northeast of the Golden Gate Bridge toll plaza and 28 miles north of Fremont, California, in the Berkeley Hills. These localities are near the headwaters of the San Leandro Creek. Only two notable sources are located here: A primary geologic source and a secondary San Leandro Creek (float) source. The archaeological evidence indicates the presence of many additional sources in the area. Because of the steep terrain, dense undergrowth, and inaccessible private property, these locations are yet to be found and fingerprinted. The quality of this chert is relatively good, and could be mistaken for a poor quality obsidian. At some archaeological sites within the San Francisco Bay Area, this material occurred and was mistaken for obsidian.

Canyon City locality C1, occurs as stream float in the bed of San Lorenzo Creek, near its headwaters. This relatively minor source can be found just south of the town's post office, 3.60 miles up the road from the Canyon City-Moraga intersection. Analyses of the chert revealed the following traits (Table 2):

- SEM analysis revealed a porous microcrystalline groundmass with occasional vugs, pockets of large (1.5-2.0 μ) colloidal material, and numerous fragments of unknown microfossils;
- EDX disclosed the following elemental content; silica (89%), aluminum (9%), potassium (1%), and a trace amount of iron (<1%); and
- However, no further analyses (FIMS) were performed on this chert because of its proximity to another tested geologic source.

Canyon City locality C2 (#A05902) is in a road cut just above and west of Canyon City. The chert outcropping is geologically in situ within the Claremont Formation. It was located 5.15 miles north of the Canyon City-Moraga intersection. In this vicinity, Monterey Group Formation outcrops throughout the Berkeley Hills which are considered to be located within a few kilometers of where they were originally formed (Case 1963). Monterey Group Chert from this locality is more like a siliceous black shale than a true chert, but is of relatively good quality. Analyses of the chert revealed the following traits (Table 2):

- SEM revealed a porous microcrystalline groundmass with vugs and pockets of free colloids, typical of MB Chert;
- EDX disclosed the following elements; silica (88%), aluminum (10%), potassium (1%), and a trace amount of calcium (<1%); and
- FIMS produced a unique histogram pattern and the petroleum biomarkers were conspicuously absent (Figure 33).

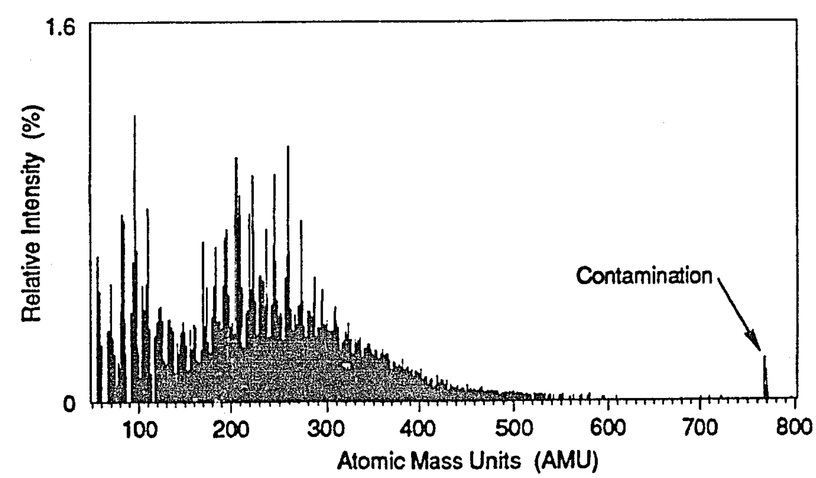


Figure 33. FIMS analysis (#A05902) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Canyon City locality C1.

Hunter Liggett. Hunter Liggett sources are 49 miles southeast of Monterey, 14 miles southwest of King City, and 50 miles west of Coalinga on restricted U.S. Government property known as Fort Hunter Liggett. MB Chert occurs at many locations on the Hunter Liggett property and is of very good quality. Field observations revealed that this area produced a large percentage of the amber variety of MB Chalcedony in addition to copious amounts of the typical MB Chert. MB Chert cobbles were so plentiful in the vicinity that many were used in the construction of Mission San Antonio. They were incorporated into cobble floors and the cobble foundations of the mission's adobe walls. At this locality, outcrops of the Monterey Shale Formation can be found throughout the eastern side of the Santa Lucia Mountain Range.

Hunter Liggett locality H1 (#A05901) is a small outcropping of Monterey Shale within the bed of Mission Creek. The locality is about 20 meters northwest of the H2 location and 30 meters north of the H3 location. The outcrop contained a small, 3 x 10 cm, lens of MB Chert. The chert is dark brown (Munsell 7.5YR, 2/0), opaque, and had no apparent banding. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and large pockets of free colloids;
- EDX disclosed pure silica; and
- FIMS produced a unique histogram pattern. Petroleum biomarkers were visible around 500 amu (Figure 34).

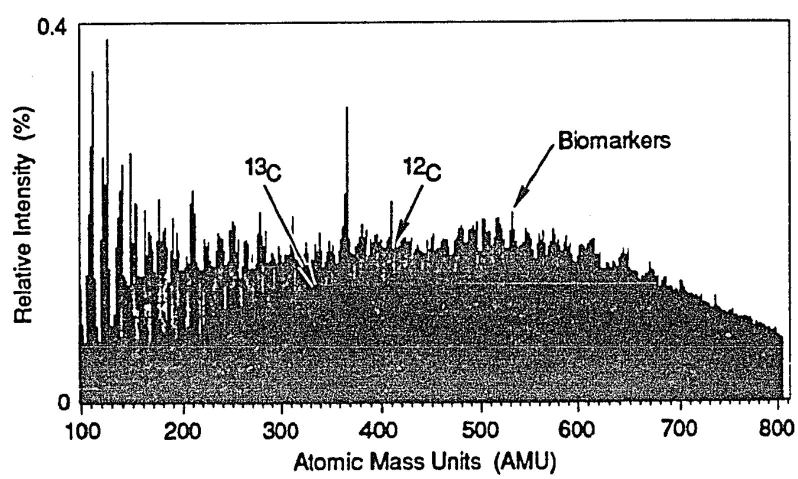


Figure 34. FIMS analysis (#A05901) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Hunter Liggett locality H1.

Hunter Liggett locality H2 (#A19602) is a slickenside deposit within the Monterey Shale Formation. The deposit contains many small, thin, and deformed lenses of MB Chert. A slickenside deposit is a geologic indicator of fault activity within the formation. This location is about 1.8 miles north of the San Antonio Mission, near the old mission reservoir, and just east of the dirt road along Mission Creek. The color of the formation at this location is a light tan (Munsell 5YR, 8/1). The MB Chert occurring here is a very dark brown (Munsell 7.5YR, 3/0), has no visible banding, and is opaque. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with a few vugs and pockets of free colloids;
- EDX disclosed pure silica; and
- FIMS produced a unique histogram pattern. The typical petroleum biomarkers were not present in this sample (Figure 35).

A possible explanation for the absence of petroleum biomarkers in the sample could be that the geologic forces responsible for the slickenside could have also collapsed the porous structure containing the petroleum.

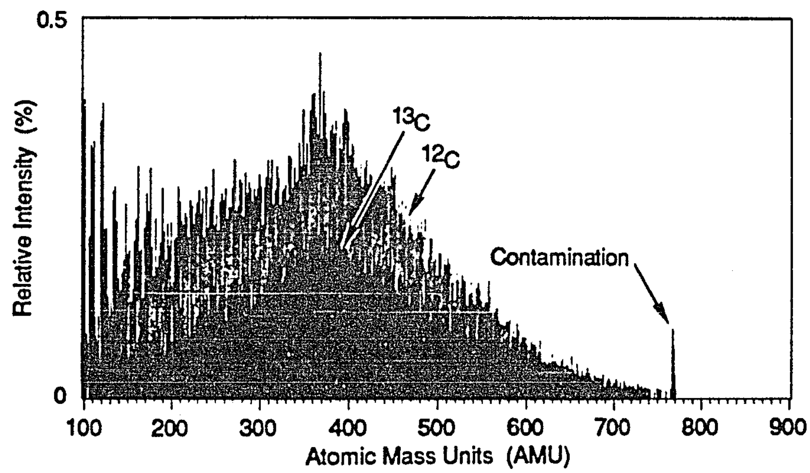
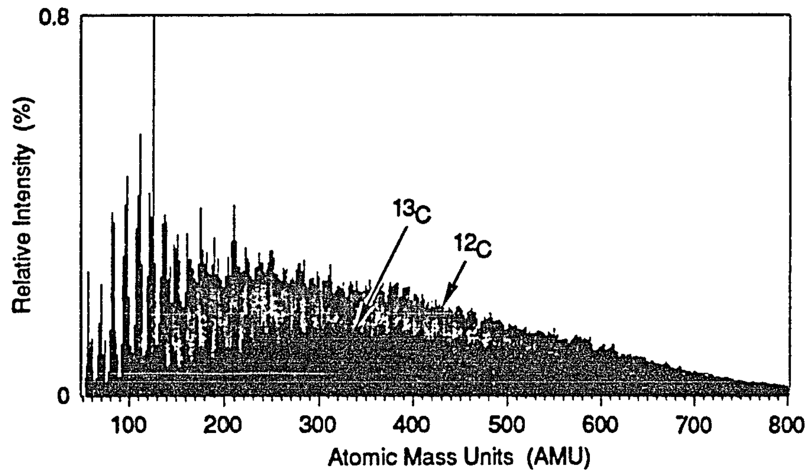


Figure 35. FIMS analysis (#A19602) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Hunter Liggett locality H2.

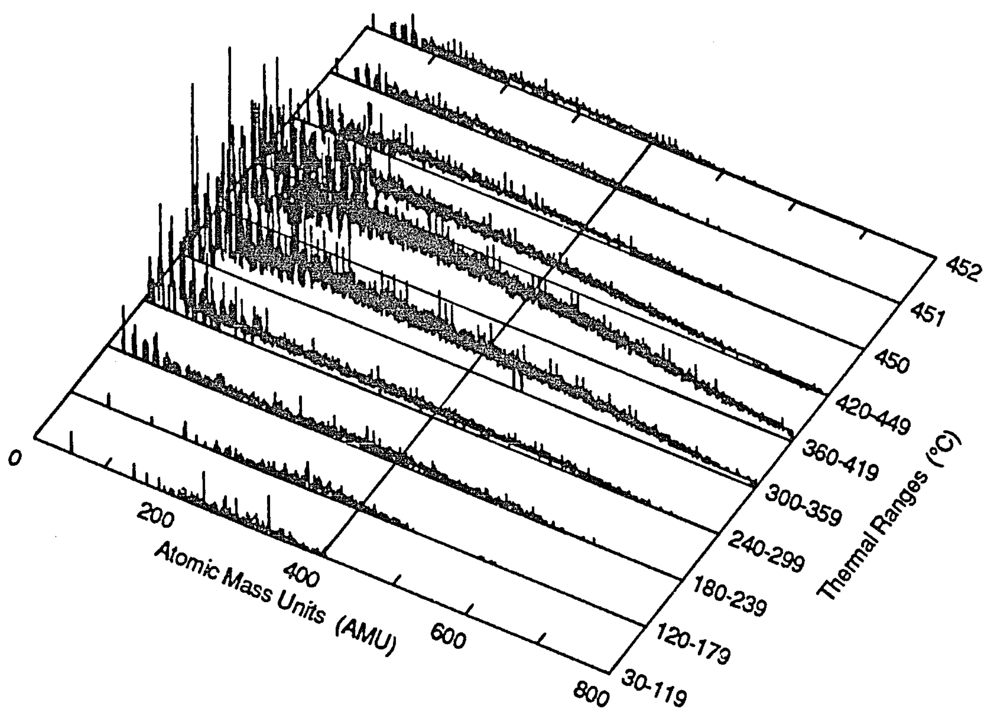
Hunter Liggett locality H3 (#A15903) is located 50 meters west of the previous two locations, H1 and H2. The outcropping occurs on an old stream terrace of Mission Creek where the terrace protrudes from the hillside, west of the dirt road along Mission Creek. The MB Chert outcropping is nearly horizontal, 21 cm thick, and was within the apex of a northeast plunging anticline. The color of the MB Chert is artificially gray (Munsell 7.5YR, 2/0), opaque (it was once black and translucent), and is faintly banded black (second-order). The reason for the specimen's gray color and opaqueness is that these samples were collected from an artillery impact crater, and the chert had been thermally altered. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and large pockets of free colloids;
- EDX disclosed pure silica; and
- FIMS analysis produced a histogram pattern (Figure 36) that was very similar to the Año Nuevo material. Typical petroleum biomarkers were not present in the sample.

The absence of petroleum biomarkers was most likely due to thermal alteration caused by the Army's impact device. Because of the similar histogram pattern of this sample with Año Nuevo material, the FIMS data was replotted three-dimensionally by its thermal ranges. Hunter Liggett sources exhibited a higher hydrocarbon content, higher volumes of low mass aromatics, and much greater high mass material than any of the Año Nuevo lithics.



(a) Histogram of SUM spectra.



(b) Three-dimensional thermal separation of SUM spectra.

Figure 36. FIMS analysis (#A15903) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Hunter Liggett locality H3.

Hunter Liggett locality H4 contains moderate sources of good quality MB Chert. This general source resulted from stream float, fluvial deposits, and talus along the hillsides within the lower Sulphur Springs Canyon. MB Chert and Chalcedony occur in many colors as stream-worn pebbles and cobbles at this source. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and large pockets of free colloids;
- EDX disclosed pure silica; and
- No additional analyses (FIMS) were performed on this material due to its proximity to other tested geologic occurrences.

Hunter Liggett locality H5 is another general area containing moderate sources of good quality MB Chert and Chalcedony. Here, MB Chert is found as stream float within most of the San Antonio River Valley that bisects the military base, and it occurs in many colors as stream-worn pebbles and cobbles. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and large pockets of free colloids;
- EDX disclosed pure silica; and
- No additional analyses (FIMS) were performed on this material due to its proximity to other tested geologic occurrences.

<u>Point Arena.</u> The Point Arena Cove locality (#A09101) is 104 miles northwest of the Golden Gate Bridge toll plaza and 37 miles south of Fort Bragg. This source produced poor quality cobbles of Monterey Group Chert. The chert was found on the beaches (float) and as isolated plates occurring within bituminous sandstone members of the formation. A few small pebbles of fair quality MB Chert were found within the beach gravels, about a half mile south of the point. In this vicinity, the Monterey Formation (formerly Point Arena Formation) outcrops along the coast in a thin triangular block 2,160 ft thick. The formation is predominantly siliceous mudstone and siltstone that grade into nearly pure silty porcelanites and chert lenses, nodules were rare. This formation may be a Santa Cruz Mudstone Formation and not a true Monterey Shale Formation.

The formation is divided into three biological units. The upper (360 ft) and lower (800 ft) parts of the formation are nonbiosiliceous, while the middle (900 ft) is biosiliceous. Most of the exposed sandstone of this formation exhibit traces of petroleum, while others exhibit total saturation. This rhythmically bedded formation shows signs of extensive reworking by bottom-dwelling oxic organisms, indicating a very different depositional environment from the Monterey Shale Formation (Boyle 1965). The formation is in direct fault contact (San Andreas Fault Zone) with the Gallaway Formation to the east. Microfossils place the age of the formation within the Lower to Middle Miocene (Boyle 1965). Analyses of the chert revealed the following traits (Table 2):

- SEM revealed a unique cryptocrystalline groundmass. It exhibited a fused or amorphous structure with many small pockets of porous free colloidal material;
- EDX disclosed a relatively large amount of silica (90%) and small amount of aluminum (10%); and
- FIMS produced unique histogram patterns. Petroleum biomarkers were visible in the vicinity of 500 amu (Figure 37).

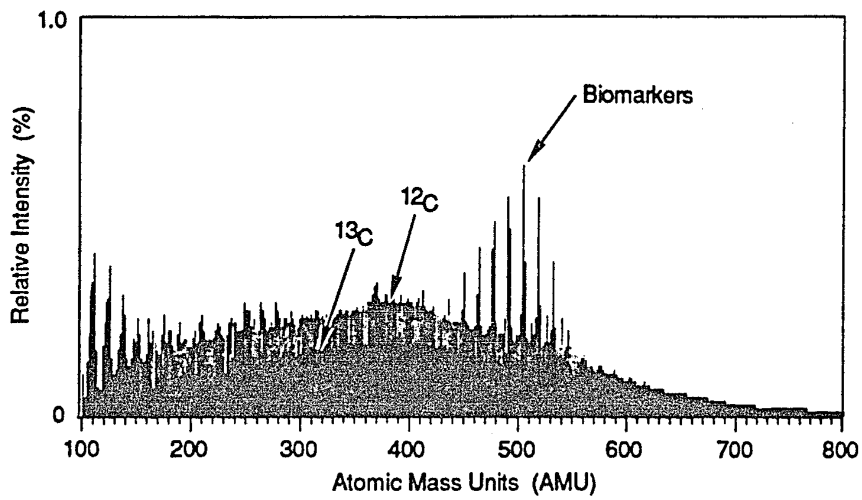


Figure 37. FIMS analysis (#A09101) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Point Arena locality.

San Ardo. The San Ardo locality (#A04101) is 73 miles southeast of Monterey and 30 miles southwest of Coalinga on restricted private property. Lithic samples were collected from Sargent Canyon's south rim, in a road cut, at the top of the ridge, near the mouth of the canyon. After surveying the area around this locality and reviewing geologic maps, it was determined that this formation was not a Monterey Group Formation. The chert originating from this location was similar to some varieties of MB Chert found in the Hunter Liggett area. The chert was semitranslucent, milky purple (Munsell 2.5YR, 6/2), no banding, and contained white fluffy inclusions (Munsell 5YR, 8/1) found in many MB Cherts and Chalcedonies. Because this lithic material was sometimes mistaken for a variety of MB Chert, it was analyzed. Analysis proved this material to be a variety of chalcedony, locally known as sard, and not a MB Chert. Analyses of the chalcedony revealed the following traits (Table 2):

- SEM revealed a nonporous cryptocrystalline colloidal groundmass;
- EDX disclosed an elemental content of silica (85%), aluminum (10%), potassium (5%), and a trace amount of iron (<1%); and
- FIMS analysis produced a unique histogram pattern. Petroleum biomarkers were nonexistent and the hydrocarbon content was extremely deficient (Figure 38).

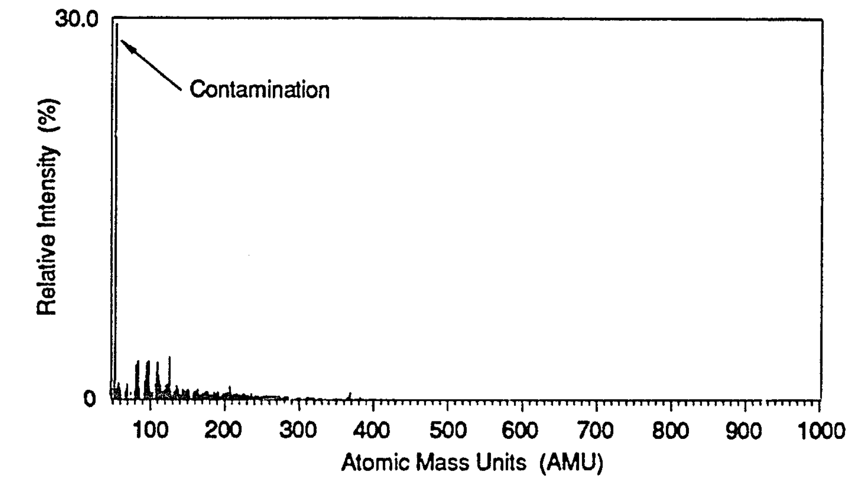


Figure 38. FIMS analysis (#A04101) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the San Ardo locality.

San Pablo. The San Pablo Dam locality (#A26506) is 14 km east of the Richmond/San Rafael Bridge toll plaza. Also, 15 km northeast of the Oakland/San Francisco Bay Bridge toll plaza. This source area is, in reality, two entirely different locations, one on either side of San Pablo Reservoir. The reservoir extends in a northwest-to-southeast direction and separates two different segments of the Monterey Group Series. The northeast segment is a Middle Miocene Marine Formation that did not produce any chert. However, the southwestern segment was a Middle to Lower Pliocene Nonmarine Formation that produced a black chert resembling Black Franciscan Chert. Analyses of the chert revealed the following traits, typical of MB Chert (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed a pure silica content; and
- FIMS analysis produced a unique histogram pattern. However, petroleum biomarkers were not visible at 500 amu (Figure 39).

The groundmass appeared fused under the SEM and contained many thermal fractures, as if heat-treated, similar to the Point Arena material.

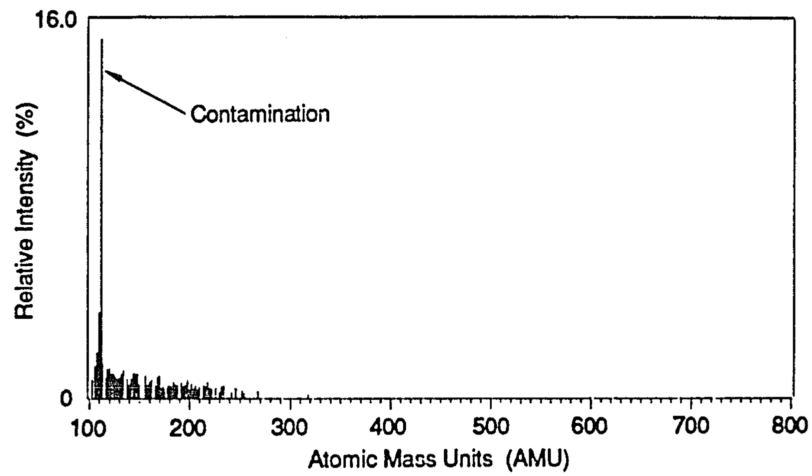
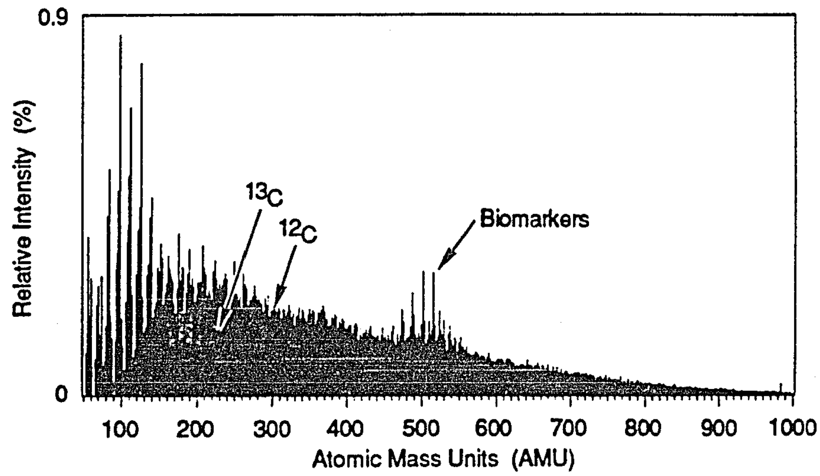


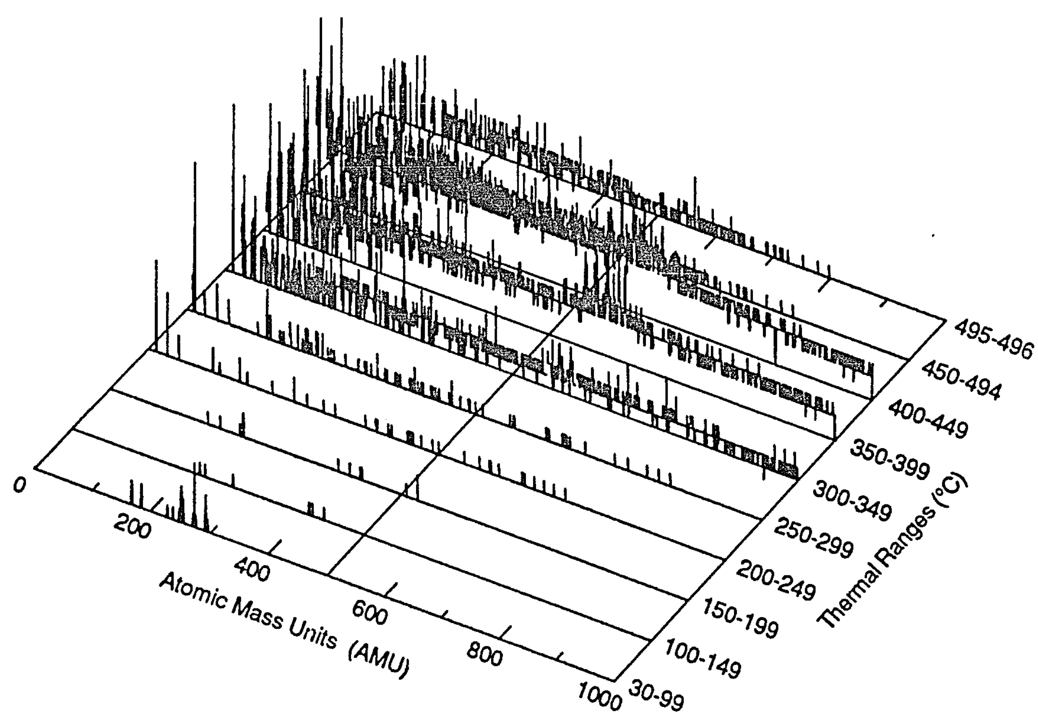
Figure 39. FIMS analysis (#A26506) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the San Pablo Dam locality.

<u>Schooner Gulch.</u> The Schooner (Skooner) Gulch locality (#A04102) is 99 miles northwest of the Golden Gate Bridge toll plaza, just west of the coast highway. MB Chert can be found here as float along ocean beaches and imbedded within the formation's bituminous sandstone members. It occurs as small isolated cobbles or plates, and the chert is of poor quality, only two out of ten cobbles were of knappable quality. The Monterey Formation (formerly Schooner Gulch Formation) is a light tan color (Munsell 5YR, 5/1), and is 2,160 ft thick at this locality. The formation was divided into three biological units. The upper 360 ft and the lower 800 ft of the formation were nonbiosiliceous, while the middle 900 ft was biosiliceous. The formation shows signs of extensive reworking by shallow water, and oxic loving bottom-dwelling organisms. This indicated a very different depositional environment from the rest of the Monterey Group Formations (Boyle 1965). The entire formation is in direct fault contact (San Andreas Fault Zone) with the Gallaway Formation to the east. Microfossils place the age of the formation within the Lower to Middle Miocene (Boyle 1965). Analyses of the chert revealed the following traits (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and large pockets of free colloids, typical of MB Chert;
- EDX analysis disclosed an elemental content of silica (89%) and aluminum (11%), not typical of MB Chert; and
- FIMS analysis produced a histogram pattern (Figure 40) similar to the Año Nuevo material. Petroleum biomarkers were visible at about 500 amu.



(a) Histogram of SUM spectra.



(b) Three-dimensional thermal separation of SUM spectra.

Figure 40. FIMS analysis (#A04102) of aromatic hydrocarbons contained within a Monterey Banded Chert sample collected from the Schooner Gulch locality.

Associated Lithic Localities and Their Fingerprints

To compare, fingerprint, and segregate MB Chert from other lithic materials, researchers must also analyze competitive lithic materials. Any similar lithic material that could be mistaken for MB Chert must be fingerprinted to make an accurate segregation of all lithics. Analysis of hundreds of collections during this study revealed that significant amounts of MB Chert were mistaken for either obsidian, chalcedony, or some other black chert. Conversely, obsidian, chalcedony, and other cherts have been mistaken for MB Chert. In many early archaeological reports concerning the San Francisco Bay Area, all cherts were combined under one term (chert) without any consideration for type or color. Because of incomplete and incorrect sorting and confusion about lithics, many public and private lithic collections in the Bay Area were personally reviewed as part of this study. The following pages present the analyses of several associated materials and black lithics similar to MB Chert, including Franciscan Chert, Franciscan Chalcedony, and Sierran Chalcedony.

Black Franciscan Chalcedony locality (#A15901) is a small outcropping on the east side of southern Santa Clara Valley. Because this locality is a recorded archaeological site (CA-SCL-427), its precise location will not be compromised. The quarry is located about 200 meters east of a prehistoric habitation site (CA-SCL-178). The chert outcropping is high on the hillside and protrudes from the rolling grasslands that surround it. This quarry produces good quality Franciscan Cherts in many colors, in addition to an excellent Black Franciscan Chalcedony. The chalcedony could be mistaken for obsidian or MB Chert, if found out of its geologic context.

The chalcedony occurs as a 5 cm thick lens on the north side of the outcropping. This small lithic source had been heavily exploited by prehistoric people, as is evident by the extensive lithic scatter surrounding the area. Black Franciscan Chalcedony is relatively common within the western portion of Central California's Coast Range. The majority of black sedimentary rocks can attribute their dark color to the organic matter they contain (Pettijohn 1957). Analyses of the chalcedony revealed the following traits (Table 2):

- SEM revealed a nonporous cryptocrystalline groundmass;
- CI of 1.6, typical of a chalcedony;
- EDX disclosed a pure silica content; and
- FIMS analysis produced a unique histogram pattern (Figure 41). There were no petroleum biomarkers and very few hydrocarbons present, typical of most chalcedonies.

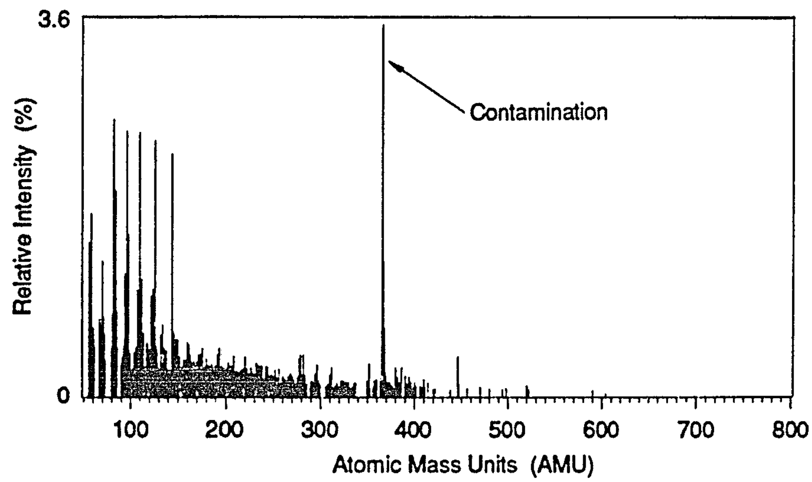


Figure 41. FIMS analysis (#A15901) of aromatic hydrocarbons contained within an associated lithic sample of Black Franciscan Chalcedony collected from the southern Santa Clara Valley.

Black Sierran Chalcedony locality (#A05903) is found in a small outcropping in the foothills of California's Central Sierra Nevada, in southern Calaveras County. Because this site was a prehistoric habitation or task-specific quarry site (CA-CAL-1243), it's exact location will not be given. The site is situated high on a ridge above the North Fork of the Stanislaus River, in an upland meadow, immediately adjacent to CA-CAL-13. The chalcedony originates from a small outcropping protruding through the grassy meadow and the outcropping is surrounded by massive limestone formations.

The quarry produces a good quality black chalcedony that contains faint growth rings of lighter material. This feature resembles the familiar banding of MB Chert. If found out of its geologic context, this material could be mistaken for MB Chert. This small source of chalcedony was heavily exploited prehistorically, since the surrounding area revealed a large lithic scatter. Black chalcedonies or any other black chert are not common in California's Sierra Nevada Foothills (Moratto 1986). Analyses of the black chalcedony revealed the following traits (Table 2):

- SEM revealed a nonporous cryptocrystalline groundmass;
- EDX disclosed an elemental content of silica (99.9%) and a trace amount of calcium (<0.1%). This trace of calcium is thought to be contamination from the host limestone formation that surrounds this outcropping and not part of the fingerprint;
- CI of 1.4 indicated this sample was a chalcedony and not a MB Chert; and
- FIMS produced a typical chalcedony pattern (Figure 42).

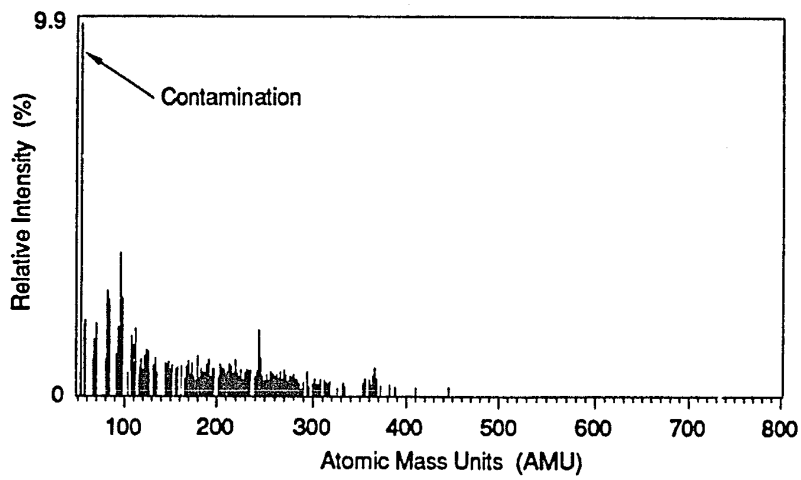


Figure 42. FIMS analysis (#A05903) of aromatic hydrocarbons contained within an associated lithic sample of Black Sierran Chalcedony collected from southern Calaveras County.

Black, Green, and Red Franciscan Chert localities (#A26507, #A31102, and #A02001) can be found as float in many stream beds throughout Central California. Even though many source areas for Franciscan Chert exist in Central California's coastal range, only three chert samples were tested. This was done because their additional analysis would not substantially enhance this report. Franciscan Cherts are characterized by their opaque earthy color, rough texture, random white veinlets, and usually of poor quality. However, in all cases of the samples tested, the Franciscan Chert displayed a distinct microcrystalline structure. Therefore, SEM and EDX were the only analyses needed for a proper identification. Analyses of the cherts revealed the following traits (Table 2):

- SEM analyses of all three Franciscan Cherts revealed a well-crystallized nonporous microcrystalline groundmass;
- EDX of Black Franciscan Chert disclosed silica (96%), iron (3%), and a trace amount of manganese (<1%);
- EDX of Green Franciscan Chert disclosed silica (90%), aluminum (7%), potassium (3%), and trace amount of iron (<0.1%);
- EDX of Red Franciscan Chert disclosed silica (86%), aluminum (7%), potassium (4%), and iron (3%);
- CI's of 9.5, 9.2, and 8.8 indicated that these samples were Franciscan Chert and not some other material; and
- FIMS produced unique histogram patterns (Figure 43), typical of most Franciscan Cherts.

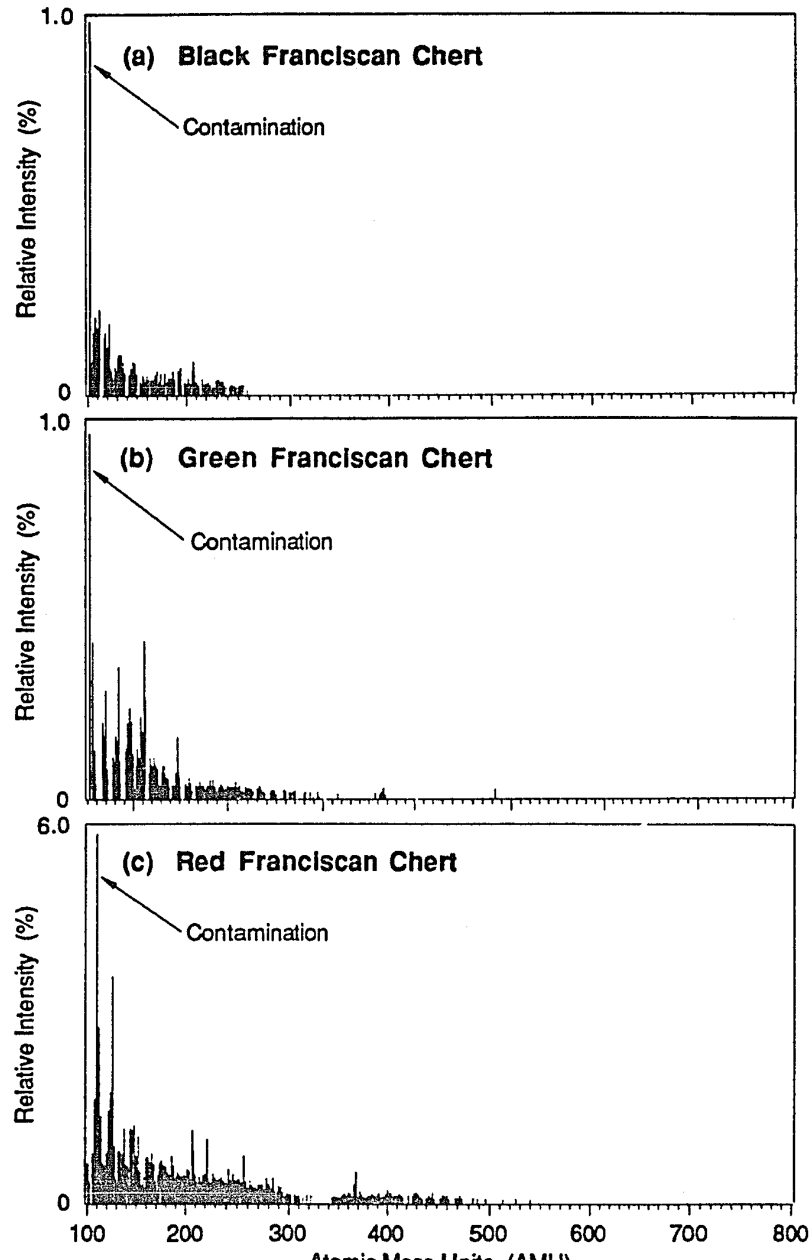


Figure 43. FIMS analyses (#A26507, #A31102, and #A02001) of aromatic hydrocarbons contained within associated lithic samples of Franciscan Chert collected from various locations in Central California's Coast Range.

Red coastal jasper locality (#A31101) is from the southern San Mateo coast, at Año Nuevo Point. This source area is 44 miles southeast of the Golden Gate Bridge toll plaza, and 22 miles northwest of the Santa Cruz City Limits. The only reason red jasper is being discussed here is that it is commonly found in coastal middens and mistaken for Red Franciscan Chert. The presence of what was thought to be Red Franciscan Chert was misinterpreted to mean that Franciscan Chert was prehistorically traded over the Santa Cruz Mountains from inland sources. Since the stone was found to be local jasper and not imported chert, conclusions regarding trade networks need to be reevaluated. Red jasper can be found at many localities around Año Nuevo Point, but it is predominantly found on the southern beaches as fist-sized cobbles of fair quality. Analyses of the red coastal jasper revealed the following traits (Table 2):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids, similar to MB Chert;
- EDX disclosed an elemental content of silica (88%), aluminum (11%), including trace amounts of potassium (<1%), and calcium (<1%);
- A CI of 3.5 indicated that this sample was a jasper and not chert; and
- FIMS produced a unique histogram pattern (Figure 44).

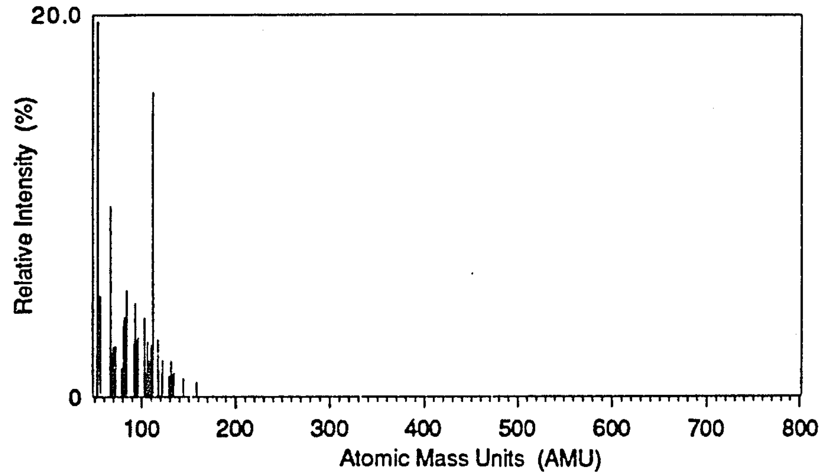


Figure 44. FIMS analysis (#A31101) of aromatic hydrocarbons contained within an associated lithic sample of red coastal jasper collected from the southern San Mateo County coast.

Summary of Geologic Source Materials

Analysis of 87 lithic samples from 31 geologic locations (Table 2) throughout Central California has established that each geologic source contained characteristic components that were detectable. Six of these geologic locations proved to be true MB Chert sources while 6 others were MG Chert localities (Table 1). The remaining 19 geologic locations were pseudo or associated lithic materials found throughout Central California's Coast Range. The reason these materials were examined was that some of them could be mistaken for MB and MG Chert. The following list briefly explains what each analyses specifically disclosed within various lithic samples;

- FIMS analysis proved that each geologic source of MB Chert contained unique hydrocarbon complexes (Figure 45) that supports the earlier sourcing model.
- SEM analysis revealed that sources like Point Arena, Canyon City, and San Pablo Dam contained unique structures that were important for their segregation.
- EDX analysis disclosed that all true MB Cherts, Franciscan Chalcedony, and Point Arena material contained only pure silica, while other Monterey Group Cherts and associated lithics contained trace elements.
- XRPD analysis discovered that even though MB Chert contained only pure silica, it manifested itself into two distinct forms, α-quartz and β-cristobalite. The α-quartz suggested a calm deep water environment,

while the β-cristobalite indicated a near terrestrial association, both typical of a back-ark basin. and

- CI was able to differentiate between the various types of hydrosilicates to make proper lithic segregations. This included agate, chalcedony, chert, flint, jasper, opal, and quartz (Figure 24).

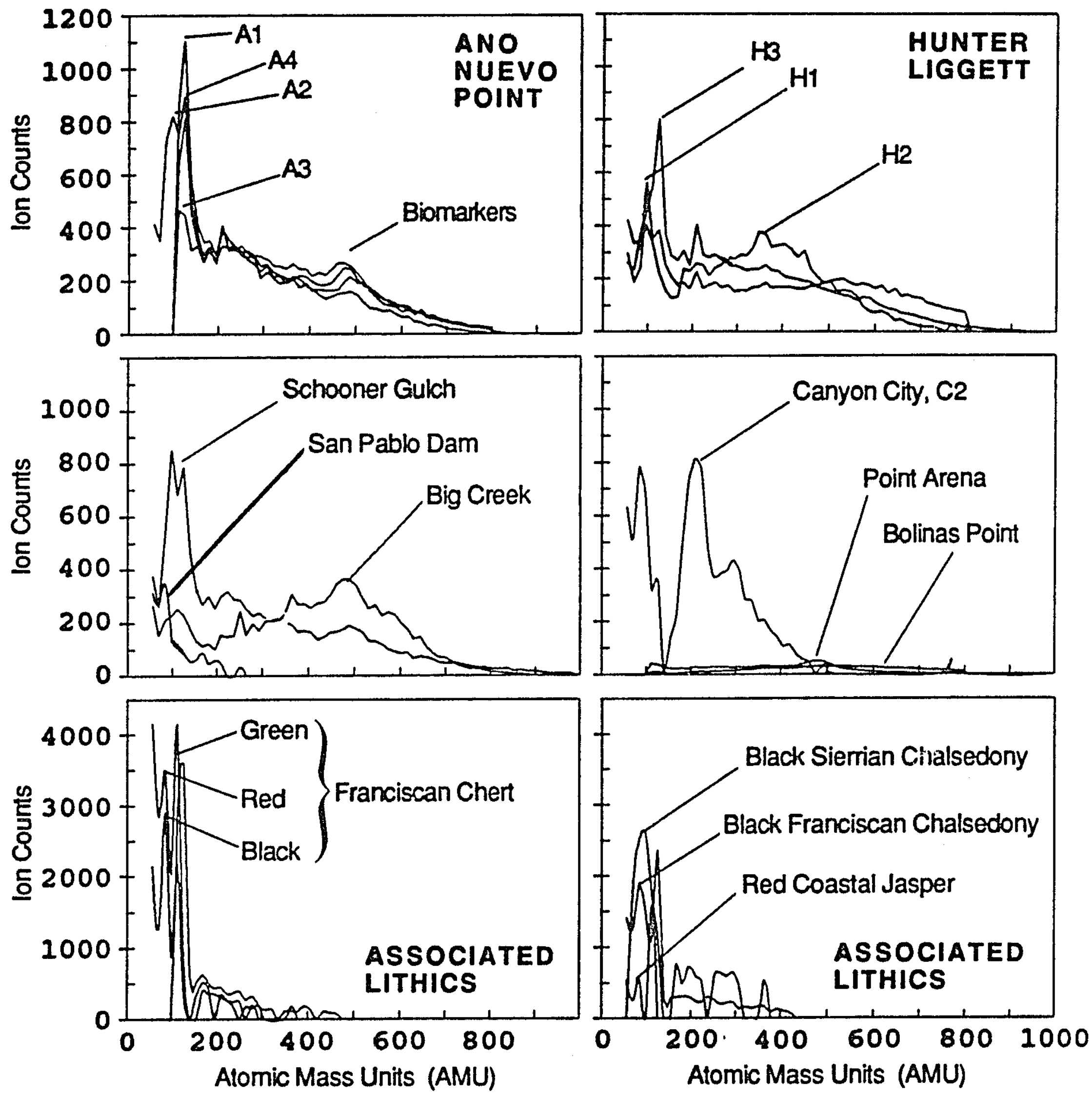


Figure 45. Profiles of unsaturated hydrocarbons (12C) obtained from all geologic sources of Monterey Banded Chert.

The above techniques have demonstrated their ability to differentiate between distinct lithic sources of chert (hydrosilicates) and reveal each source's unique fingerprints. Initially, some confusion was caused by overlapping of source data. Further manipulation, reduction, and replotting of the data eliminated this confusion. As stated previously, the FIMS technique is a well-established tool used by the petroleum industry to fingerprint each petroleum reserve. Geologists have discovered that each unique fingerprint is persistent, even after the original source material has been processed into gasoline. FIMS analysis of petroleum fractions within MB Chert is a reliable and definitive method for the determination of each unique geologic source. Now FIMS can be reliably applied to artifactual materials manufactured from MB Chert and other materials. It has demonstrated the ability to produce consistent results, even after thermal alteration.

Even though a detailed description of each geologic source of MB Chert has been given, a synopsis of distinguishing characteristics of each would be helpful. All true MB Cherts have cryptocrystalline structures and contain only silica, with no trace elements of any kind. They are marginally translucent, and usually well banded. MB Chert occurs in all shades of brown, including white and gray, with dark-brown being the predominant color.

There are two known major sources of MB Chert in Central California are (from north to south) Año Nuevo Point and Hunter Liggett Military Reservation.

1. All MB Chert from the Año Nuevo sources area are characterized by high concentrations (~800 cts) of unsaturated (U1) hydrocarbons (^{12}C) at low mass (~100 amu), a moderate concentration (~400 cts) at ~200 amu, and a third concentration (~200 cts) occurring around ~500 amu. This last concentration is being called a biomarker. Año Nuevo material produces a consistent shallow concave wedge shape or slope (of ~30°) of U1 material, with prominent peaks at ~100, ~200, and ~500 amu that terminates at ~1000 amu.

2. Most MB Cherts from the Hunter Liggett source area are characterized by moderately high concentrations (~500 cts) of unsaturated (U1) hydrocarbons (^{12}C) at a low mass (~100 amu), a second moderate concentration (~300 cts) occurring at 200 amu, and a third minor concentration (~200 cts) occurring at ~350 amu. Only one MB Chert sample yielded any biomarkers at ~500 amu (Figure 45). However, when the SUM spectra was replotted by its thermal ranges, the chert yielded a noticeably greater amount of hydrocarbon material over a broader thermal spectrum (Figure 36) than did any Año Nuevo specimen (Figure 30). Hunter Liggett specimens were noted for their inconsistency, each yielded a different histogram pattern. However, all exhibited lessor amounts of hydrocarbon materials at low masses

and greater amounts at higher masses than did the consistent Año Nuevo material. This trait produced a more uniform slope (of ~30°) or wedge shape pattern of U1 material that terminated at ~1000 amu.

There are also four known minor sources of MB Chert in Central California, they are (from north to south) Point Arena Cove, Schooner Gulch Cove, Bolinas Point, and Big Creek.

1. All MB Chert from Point Arena sources yielded very few hydrocarbons, flat U1 curves, and produced very distinct biomarkers at ~500 amu. A trace element of Aluminum (Al) was discovered by the EDX procedure. While under SEM, a unique structural pattern was observed that resembled a fussed groundmass with evenly spaced pockets of free colloidal material.

2. All MB Chert from the Schooner Gulch source area exhibited SUM spectra and U1 traces that were similar to Año Nuevo material. However, when the FIMS data was replotted by thermal ranges it yielded very few hydrocarbons at low temperatures and noticeably greater amounts at higher thermal ranges. These samples also contained a small trace element of Aluminum (Al) and a groundmass structure that was similar to Schooner Gulch material.

3. All of the MB Chert from the Bolinas Point source contained only pure silica and extremely small amounts of hydrocarbon material, very

similar to Point arena. Even though it contained very little ^{12}C, it produced a histogram pattern similar to a Hunter Liggett (H1) source.

4. All MB Chert from the Big Creek source area produced histogram patterns similar to Point Arena material. However, its' U1 trace contained noticeably larger amounts of hydrocarbon material. The structure and elemental content of the specimens were identical with most Año Nuevo material.

In addition to the above four sources of true MB Chert, there are several MG Chert and pseudo sources in Central California (Table 1). MG Chert sources discovered are Point Arena Cove, Schooner Gulch, San Pablo Reservoir, Canyon City. In addition to these, numerous Black Franciscan Chert localities exist throughout Central California. There are also two known sources of a pseudo MB Chert. The first is a black Franciscan Chalcedony that can be found south of San Jose and the second is a black Sierran Chalcedony that occurs north of Sonora.

1. MG Cherts are characterized by black earthy textures, an absence of banding, opaque porous structure, trace elements, large hydrocarbon content at low masses, and no petroleum biomarkers (Point Arena and Schooner Gulch are the exceptions). These cherts are closer to a siliceous shale than they are to a good quality chert.

2. Black Franciscan Cherts can be found throughout Central California's Coast Range and are occasionally mistaken for MB or MG Chert. This chert is characterized by its black earthy color, rough texture, random white veinlets, no biomarkers, no hydrocarbon content at high mass, low hydrocarbon content at low mass, well crystallized, nonporous, microcrystalline, and a CI Index between 6.2-9.5 (Figure 24).

3. Black Franciscan and Sierran Chalcedonies, if found out of their geologic context could be easily mistaken for a good quality MB Chert. These materials are characterized by their black color, smooth translucent texture, high luster, and faint banding that are in reality growth rings. They also exhibit a non-porous groundmass, pure silica, no trace elements, no petroleum biomarkers, no hydrocarbons at high mass, low hydrocarbon content at low mass, and a CI Index between 1.0-4.8 (Figure 24).

CHAPTER V: PREHISTORIC DISTRIBUTION OF MONTEREY BANDED CHERT IN CENTRAL CALIFORNIA

Early studies on the economics of obsidian trade in prehistoric California were plagued with inadequacies. These inadequacies include the absence of diverse typologies, insufficient understanding of temporal relationships, and scarcity of reputable published reports from which to extract pertinent information (Jackson 1974). Because of these shortcomings, it was difficult to understand obsidian distribution through time and space (Jackson 1974). Initial studies on the economics of Monterey Banded (MB) Chert in Central California prehistory are no different. Many obstacles were encountered in the preparation of this research report. Apparently, this situation is not unique, but has been encountered by other researchers. As eloquently expressed by another author:

> All of the above-mentioned obstacles were obviously intertwined. Without a large body of well-written, effectively descriptive literature, researchers cannot possibly hope to keep abreast of all that has occurred in California archaeology in its central history. Archaeologists are, then, forced to rely upon primary data such as museum collections, field notes, and other unpublished data sources. This reliance upon primary data sources necessitates a fantastic amount of time required to obtain information. Entire artifact collections must be inspected in search of a few worthy specimens which will accommodate the researcher's aim. Museum catalogues and collections were notoriously lacking in their ability to provide accurate information. Specimens were lost from collections or were incorrectly catalogued. Where cataloguing systems have changed in museums, the loss and misrepresentation of artifactual specimens was likely to increase. Long-standing collections, especially those in active use in educational institutions, suffer a phenomenal rate of loss due to carelessness and pilfering. Log notes and other primary records were celebrated for their uselessness and inaccuracies, especially those records of the early amateur investigations in the delta area (Jackson 1974:53).

In addition to the aforementioned obstacles described by Jackson, this research project encountered additional difficulties. Even though proper protocol was followed, access to archaeological collections housed within two public institutions was denied. Also, important artifacts which were crucial to this research project were withheld from analysis (Table 3). These problems are not limited to public institutions, but have been encountered by several private archaeological firms. Jackson makes the following statement:

> The general failure of archaeologists to rapidly make their information available on a wide scale has resulted in the trend toward a specifically regional approach in the study of California prehistory. There exists no adequate published integrative study of prehistory for the central area of California, much less the area of California as a whole. Archaeologists tend to establish elementary, descriptive listings of material prehistoric remains and present these as analyses of prehistoric cultures. It is to be emphasized that I am not opposed to the first basic step in archaeological analysis, description, nor am I opposed to the construction of local typologies and chronologies. Before archaeologists can hope to understand the workings of culture in the prehistoric record they must first learn to adequately and effectively describe what it was they have found. Without the communication of this basic information we cannot exchange ideas and information, nor may we embark upon a program of interpretation. The regional orientation of most archaeological reports in California does not afford the investigator of broad areal and temporal phenomena the opportunity for a rapid comprehension of the relationships which existed between these regions. These he must discern for himself or he must rely upon studies which describe or compare materials from adjacent areas (Jackson 1974:54).

In spite of the many obstacles, approximately 788 lithic collections (public and private) were reviewed for the presence of MB Chert. It was determined from the materials reviewed, that MB Chert had not been

Table 3
Institution and Private Collections Surveyed for Evidence of Monterey Banded Chert Occurring Within Archaeological Sites From Central California.

No.	Institutions	Remarks
01	Cabrillo, JC	Access to collections denied
02	Canada, JC	"No material"
03	San Mateo, JC	"No material"
04	Foothill, JC	All collections made available
05	Hayward State	All collections made available
06	Ohlone, JC	"No material"
07	Peninsula, JC	"No Material"
08	Sacramento State	Access to collections denied
09	San Francisco State	All collections made available
10	San Jose City, JC	"No Material"
11	San Jose State	All collections made available
12	Sonoma State	"No material"
13	Stanford University	All collections made available
14	UC Berkeley	All collections made available
15	UC Davis	No one would give access
16	UC Santa Cruz	All collections made available
17	Santa Clara University	No one would give access
18	West Valley, JC	"No material"
19	Santa Cruz Archaeological Society	All collections made available
20	Santa Clara Archaeological Society	No response

No.	Missions	Remarks
01	Carmel	Partial access granted
02	Delores	"No material"
03	San Antonio	Partial access granted
04	San Jose	Partial access granted
05	San Juan Bautista	Partial access granted
06	Santa Clara	"No material"
07	Santa Cruz	"No material"
08	Solidad	Partial access granted

Table 3
(Concluded)

No.	Museums	Remarks
01	Academy of Science	"No material"
02	Coyote Point	"No material"
03	Los Gatos	Partial access granted
04	Lowie	All collections made available
05	Oakland Public	"No material"
06	Monterey Presidio	Partial access granted
07	Pacific Grove	Partial access granted
08	San Francisco Presidio	"No material"
09	Santa Clara University	"No material"
10	Santa Cruz	All collections made available
11	Stanford University	"No material"
12	Treganza	"No material"

No.	Other Agencies	Remarks
01	Ano Nuevo State Park	All collections made available
02	East Bay Regional Park	All collections made available
03	State Beaches & Parks	All collections made available
04	Coyote Hills Park	Partial access granted
05	Archaeological Consulting	All collections made available
06	Archaeological Consulting and Research Service	Partial access granted
07	Archaeological Research Facility	Partial access granted
08	Archaeological Resource Management	Partial access granted
09	Archaeological Resource Service	"No material"
10	Archeo-Tech	No response
11	Basin Research and Associates	No response
12	Far Western Archaeological Research Group	"No material"
13	Infotech Research	"No material"

No.	Private Collections	Remarks
01	Badger	All collections made available
02	Bradley	All collections made available
03	Brown	All collections made available
04	Collins	All collections made available
05	Harris	All collections made available
06	Hoover	All collections made available
07	McCrary	All collections made available
08	Roehr	All collections made available
09	Steele	All collections made available
10	Scimeca	All collections made available

extensively traded great distances inland (Appendix B). Disregarding linguistic boundaries, distribution of MB Chert appears to inversely correspond with the proximity of obsidian sources. Where obsidian is abundant, there is no MB Chert to be found within archaeological sites (Figure 46). MB Chert appears to have been used almost exclusively by the coastal groups of Central California, far from any obsidian source. There was a conspicuous absence of MB Chert from areas that produced the favored obsidian. On the other hand, small amounts of obsidian are found in and around most prehistoric MB Chert quarries.

After reviewing numerous lithic collections (including 15 private collections) from 788 archaeological sites within Central California's Coast Range, 366 sites were found to contain true MB Chert. In addition to other local cherts, 49 sites contained MG Chert in one form or another. Thermal alteration studies of 30,458 MB Chert fragments, established that some lithics previously identified as MG Chert may have been thermally altered MB Chert (Parsons 1987). Replicative thermal studies proved that some MB Cherts change to an opaque black when heated, and they resemble Monterey Group Chert. From the total, a sample group of 30 artifacts were analyzed (8 with FIMS) from 24 archaeological sites. This research indicated the quantity, type, and distribution of MB Chert artifacts had a direct relationship to the proximity of lithic sources. Based on a model of expanding concentric circles with obsidian sources at the center, coastal sites within a 40 km radius of obsidian sources, lacked MB Chert lithics. This absence of MB Chert near obsidian sources is known as a lithic shadow. In a band beyond 40 km and within 100 km radius, occurrences of MB Chert were intermittent, changing the dominance of obsidian over MB Chert and visa versa through time. Conversely, sites close to MB Chert sources significantly lacked obsidian lithics, although small amounts of obsidian were present.

After reviewing numerous lithic collections from Central California (Appendix B) for the simple presence or absence of MB Chert, basic distribution patterns became apparent. It was also discovered that MB Chert was not traded very far inland from its coastal sources (Figure 46). Unlike MB Chert, obsidian trade was able to intrude into the MB Chert lithic shadow. Even though its occurrence is rare, obsidian was able to penetrate all the way to most MB Chert quarries.

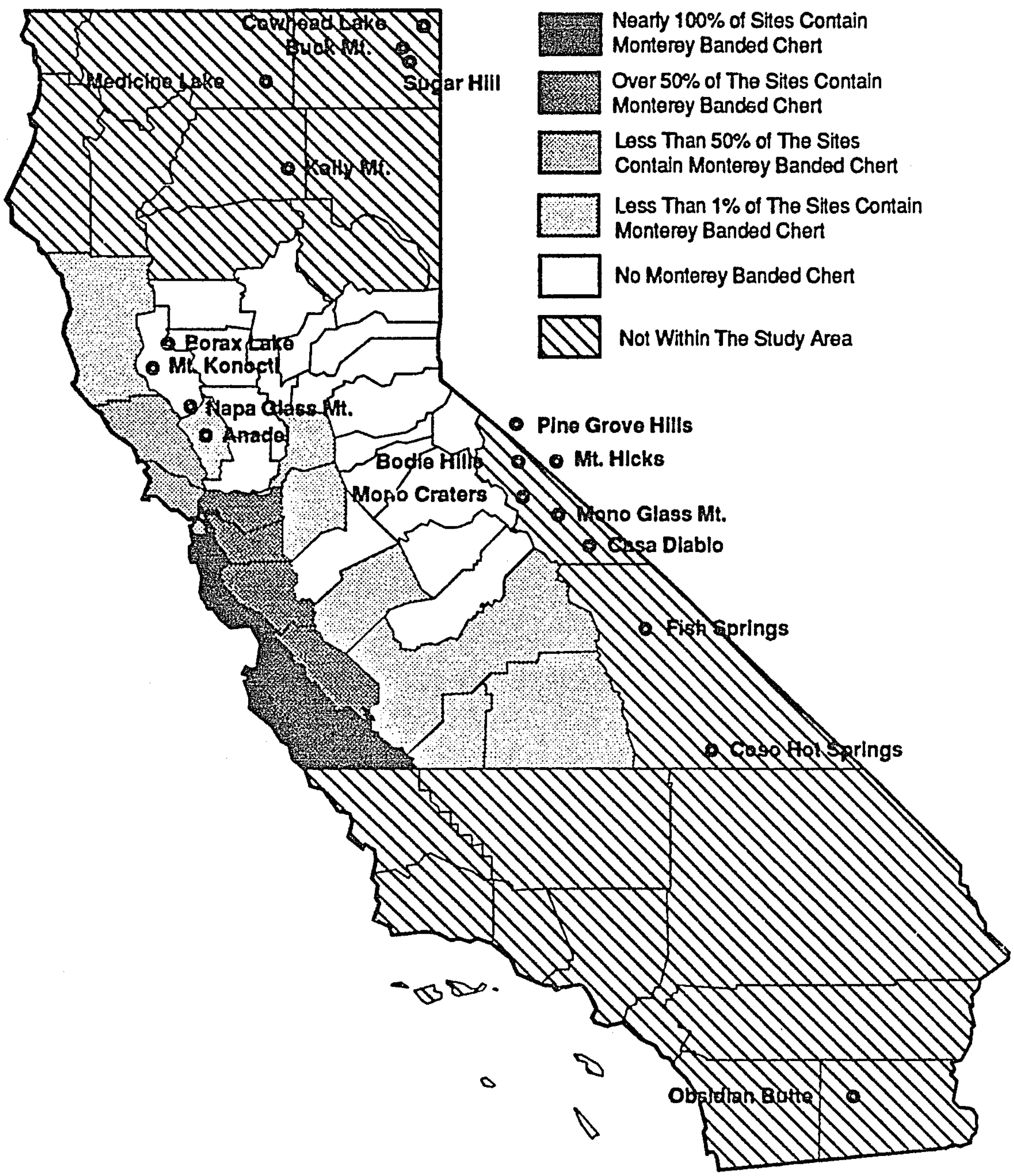


Figure 46. Distribution of Monterey Banded Chert, its sources, and obsidian counterparts in Central California.

Archaeological Specimens

Once geologic sources of Monterey Banded (MB) and Monterey Group (MG) Cherts were documented and distribution patterns established, attention was then directed towards artifacts manufactured from MB Chert. The first samples included artifacts originating from archaeological sites immediately adjacent to lithic sources. Once this baseline analysis had been accomplished, attention was then directed to sourcing the most distant archaeological occurrences of MB Chert.

Artifacts from distant sites were obtained during the extensive surveys previously discused in this chapter and through personal contacts. MB Chert artifacts were subjected to the same analytical tests performed on the geologic source materials discussed in Chapter IV, and described in Chapter III. Results obtained from the artifact analyses were compared with those obtained from the geologic source results.

During the analysis, signs of thermal alteration were noted on many artifacts. It is a well-known fact that lithic materials were prehistorically heat treated to improve their knappability (Rich and Asch 1978; Crabtree and Butler 1964). This knowledge, along with personal observations of coastal middens, led to the examination of MB Chert for thermal effects that could alter the fingerprinting process.

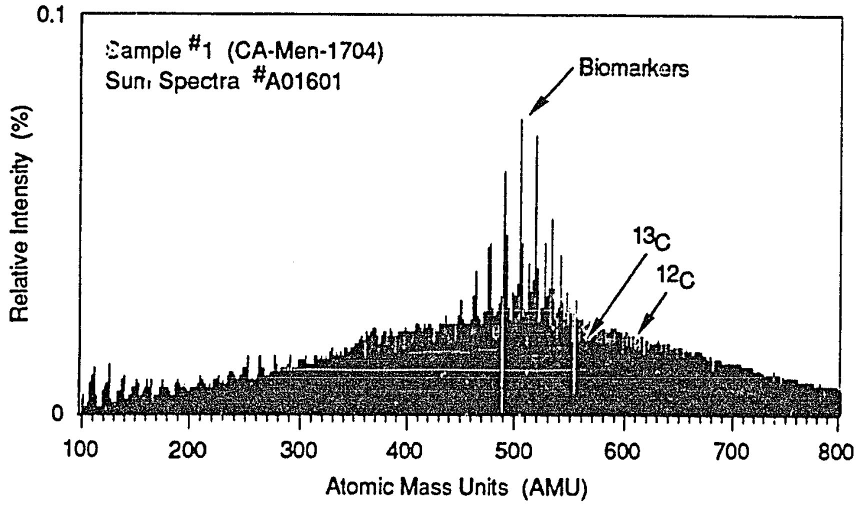
Thermal alteration of MB Chert by prehistoric people of Central California has been a controversial subject among archaeologists for some time (Rick 1988). For this investigation, a thermal study area was established, covering 460 square km of southern San Mateo and northern Santa Cruz Counties. All of the MB Chert specimens used for this analysis came from 24 archaeological sites (in situ) and 15 private collections originating from within the thermal study area. A total of 30,458 MB Chert items were examined for signs of thermal alteration. From these, 354 supposedly unaltered chert samples were selected for further analysis.

By using SEM and other analytical techniques, additional signs of thermal alteration were detected. Analysis revealed 82% +/-2% of all MB Chert artifacts and debitage from San Mateo and Santa Cruz Counties had been thermally altered. Thermal alteration was most likely performed preceding or during the knapping process (Parsons 1987). Even though most of the 354 artifacts had been heat-treated and their fingerprints altered, they were still excellent candidates for lithic sourcing. It was discovered that even though FIMS intensities were significantly lower and petroleum biomarkers sometimes absent, specimens maintained unique patterns of their parent material. California produces a large variety of hydrosilicates that resemble MB Chert. Because of this fact and to set reasonable limits on the scope of this report, a systematic process of elimination was devised. It was established that only black or near black varieties of coastal chert would receive a thorough examination (Figure 25). Further segregation of artifacts by SEM, EDX, and CI eliminated many samples at an early stage.

Sample #1. This chert specimen (#A01601) originated from a Mendocino County site (CA-MEN-1704), north of Albion, California. The site was excavated by San Jose State University students under the direction of Dr. Thomas Layton. The sample was a small MB Chert core of good quality, opaque, dark brown (Munsell 2.5Y, 2/0), with no visible banding. It contained a few tan (Munsell 10YR, 7/3) inclusions, typical of many MB Cherts. Analyses of the sample revealed the following traits that were typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed a pure silica content; and
- FIMS analysis produced a histogram pattern (Figure 47) that was very similar to the Bolinas Point source (Figure 32).

Based upon the physical and analytical evidence presented above, this chert core was identified as MB Chert. The cherts fingerprint correspond to the Bolinas Point geologic source area pattern. This artifact was quarried from the Bolinas Point area and not from the nearby Point Arena or Schooner Gulch sources, as previously thought.



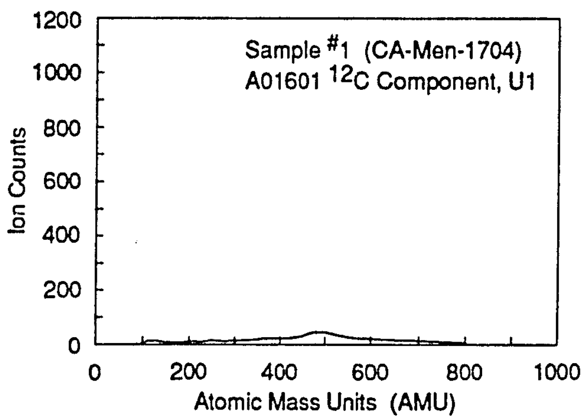


Figure 47. FIMS analysis (#A01601) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-MEN-1704) near Albion, CA.

Sample #2. Two flakes were analyzed from an archaeological site (CA-MEN-1809) north of Albion, California. They were recovered by San Jose State University, under the direction of Dr. Thomas Layton. Physical examination revealed that both flakes had been thermally altered. The chert flakes were dark brown (Munsell 10YR, 2/1), well-banded (first order) with white (Munsell 10YR, 8/1) bands, had a glassy luster, and were semitranslucent. Analyses of these chert artifacts revealed the following traits typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass containing many vugs and occasional pockets of free colloidal;
- EDX disclosed a pure silica content; and
- Destructive analysis was not performed on these materials at the request of Dr. Thomas Layton.

Based upon the limited analysis, these specimens were deduced to be MB Chert and not some other lithic material. Unfortunately these chert artifacts could not be geologically sourced; their origin could have added important pieces to a much larger puzzle.

Sample #3. This specimen (#B02102) was a relatively large bifacial tool manufactured from MB Chert. The artifact was surface collected by archaeology students from San Jose State University in 1980. This site (CA-SMA-211) was centrally located on the southern point of Año Nuevo. The chert was dark brown (Munsell 10YR, 2/1), with faint banding (first order), large layered inclusions of white (Munsell 10YR, 8/1) and tan (Munsell 10YR, 6/2) diatomaceous material. Analyses of the chert tool revealed the following traits typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloids;
- EDX disclosed pure silica; and
- FIMS analysis produced a histogram pattern (Figure 48) that was typical of most Año Nuevo sources (Figure 27).

In this sample, typical petroleum biomarkers were not discernible around 500 amu, most likely the result of prehistoric thermal alteration during the manufacturing process (Parsons 1987). Thermal alteration most likely caused relatively lower peak intensities in the histogram, compared with nearby geologic source materials (Figure 27). Based upon its physical traits, the analytical results, and the proximity to lithic sources, this tool was determined to be MB Chert. This artifact unquestionably originated from one of the numerous Año Nuevo quarry sources adjacent to the site.

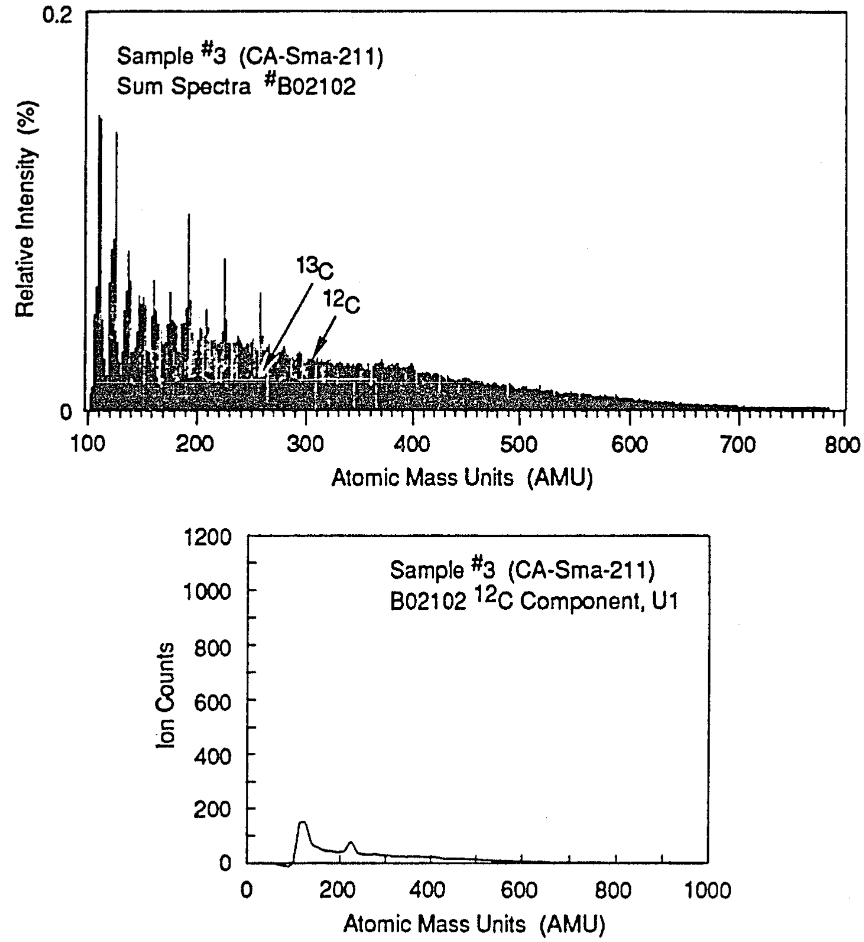


Figure 48. FIMS analysis (#B02102) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-SMA-211) near Año Nuevo Point, CA.

Sample #4. Similar to sample #3, this specimen (#B18001) was a relatively large bifacial tool manufactured from MB Chert. This artifact was surface collected from an archaeological site by students from San Jose State University in 1980. The task-specific site (CA-SMA-218) was located on the northern point of Año Nuevo. The chert was dark brown (Munsell 10YR, 2/1), well-banded (first order) with white (Munsell 10YR, 8/1) and tan (Munsell 10YR, 6/2) inclusions of diatomaceous material, and exhibited signs of thermal alteration (Parsons 1987). Analyses of this chert tool revealed the following traits, typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass with many vugs and pockets of free colloidal material;
- EDX disclosed pure silica; and
- FIMS produced a typical histogram pattern (Figure 49) for Año Nuevo chert sources (Figure 27).

Prehistoric thermal alteration was responsible for the faint petroleum biomarkers at 500 amu and the relatively lower peak intensities in the histogram (Parsons 1987). Based upon physical traits, analytical results, and its' proximity to lithic sources, this tool was manufactured from MB Chert quarried from one of the numerous Año Nuevo sources nearby.

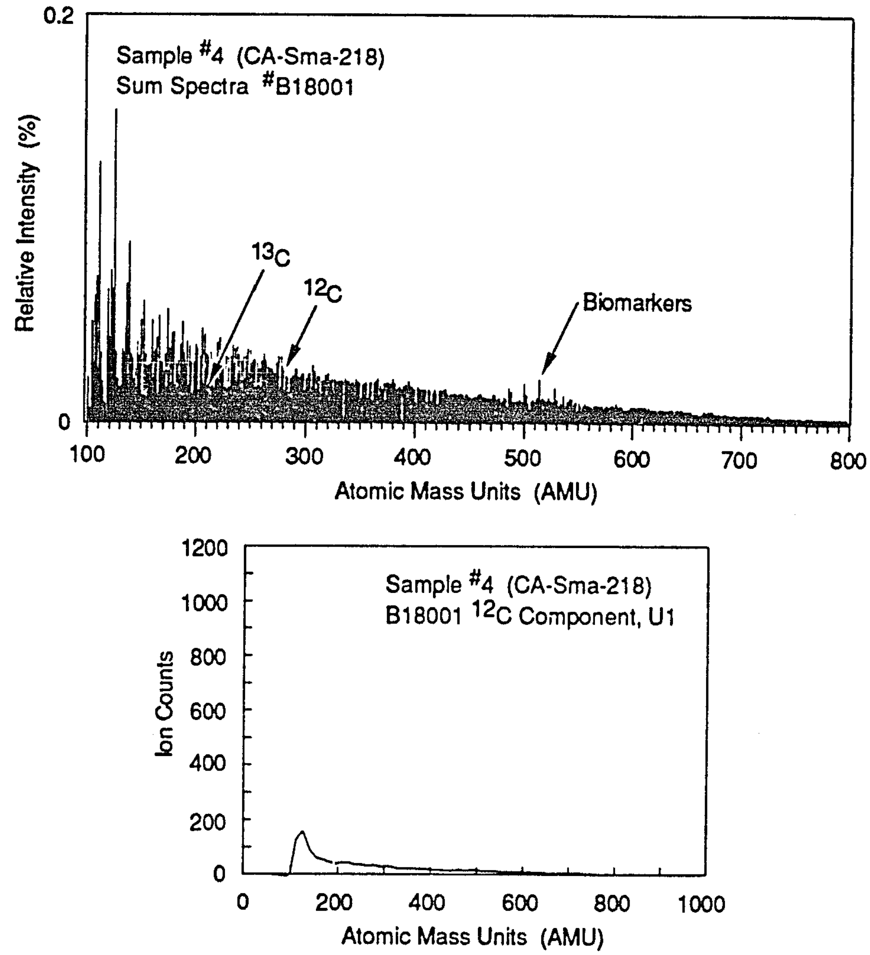


Figure 49. FIMS analysis (#B18001) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-SMA-218) near Año Nuevo Point, CA.

Sample #5. The bifacial chert tool (#A26503) was surface collected from a badly eroded archaeological site (CA-SON-295) near Bodega, California. The ocean has severely eroded the site, and only a small portion was left intact. The site was composed of 99% shell, 1% bone, less than 0.1% lithics, and a single chert artifact was collected for analysis. The chert exhibited no banding, was opaque, had a dull luster, was dark brown (Munsell 7.5YR, 2/0), and contained tan (Munsell 7.5YR, 5/2) inclusions. Analyses of the chert revealed the following traits (Table 4):

- SEM revealed a very porous microcrystalline groundmass that appeared fused, similar to the Canyon City source material;
- EDX disclosed an elemental content of silica (70%), aluminum (20%), potassium (6%), calcium (3%), and a trace amount of iron (<1%), again similar to the Canyon City source; and
- FIMS analysis produced a unique histogram pattern (Figure 50) that was similar to the Canyon City source of Monterey Group Chert (Figure 33), located in the Berkeley Hills.

The results of the analysis of this specimen are not typical of MB Chert. No petroleum biomarkers were present in the specimen at 500 amu. Based upon physical traits and analytical results, this artifact is a Monterey Group Chert. It was quarried from the Claremont Formation in the Berkeley Hills, near Canyon City, California. Although the findings were not identical with the Canyon City source, the divergent patterns could have been the result of chert not being homogeneous. More likely, this artifact originated from an untested lithic source in the Berkeley Hills, within the Claremont Formation.

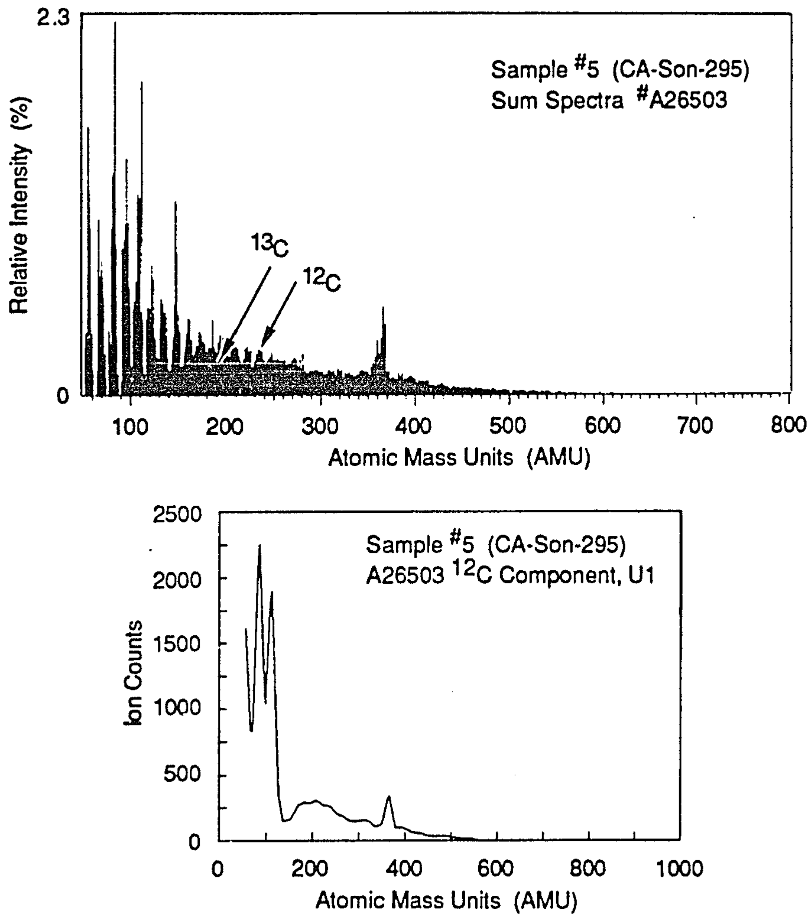
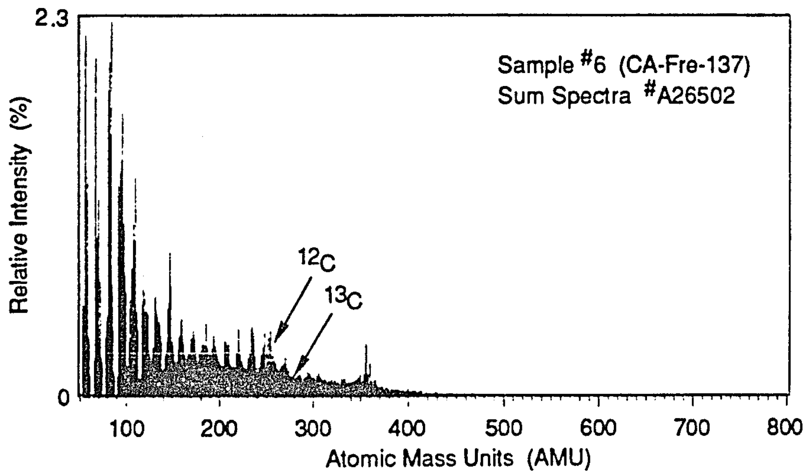


Figure 50. FIMS analysis (#A26503) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-SON-295) near Bodega Head, CA.

Sample #6. The bifacial chert tool analyzed here (#A26502) was recovered from archaeological site CA-FRE-137 near Mono Hot Springs, California (Jackson 1986). The chert tool exhibited signs of excessive over-heating, most likely due to thermal alteration during the manufacturing process (Parsons 1987). Some of the physical features of thermal alteration observed were: gray color, recrystallized groundmass, crazing, glassy luster, fused structure, and thermal fractures. The chert was light gray (Munsell 10YR, 7/1), well-banded (first order), and contained uncommon black (Munsell 10YR, 2/1) bands. Analyses of the chert tool revealed the following traits typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass containing large areas of microcrystalline material;
- EDX disclosed pure silica; and
- FIMS analysis produced a unique histogram pattern (Figure 51), similar to the Canyon City source of Monterey Group Chert (Figure 33).

No petroleum biomarkers were present in the specimen at 500 amu, unlike most MB Cherts. The absence of the petroleum biomarker, along with the fused structure, and gray color are believed to be the result of thermal alteration (Parsons 1987). Possibly the specimen never contained petroleum, and the uncommon black bands are a thermal trait of MG Chert, not MB Chert. While this specimen exhibited physical traits typical of MB Chert from Año Nuevo, it also produced fingerprints typical of MG Chert from the Canyon City source. This sample exhibited unusual physical traits and unique analytical characteristics that did not match any known geologic source. The chert most likely originated from an undocumented geologic source somewhere in California. Based upon geographic and ethnographic information, this artifact may have originated from the southwestern San Joaquin Valley or southern California, but not Central California's Coast Range.



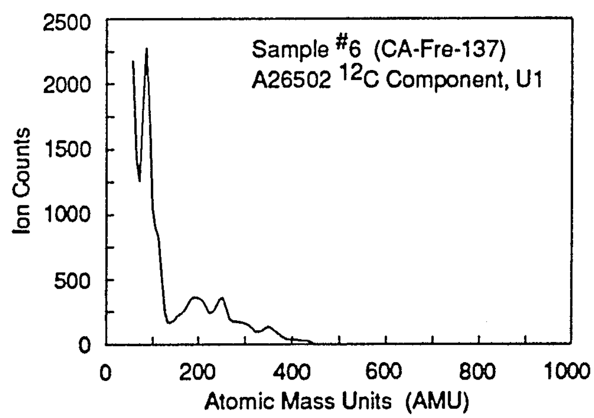
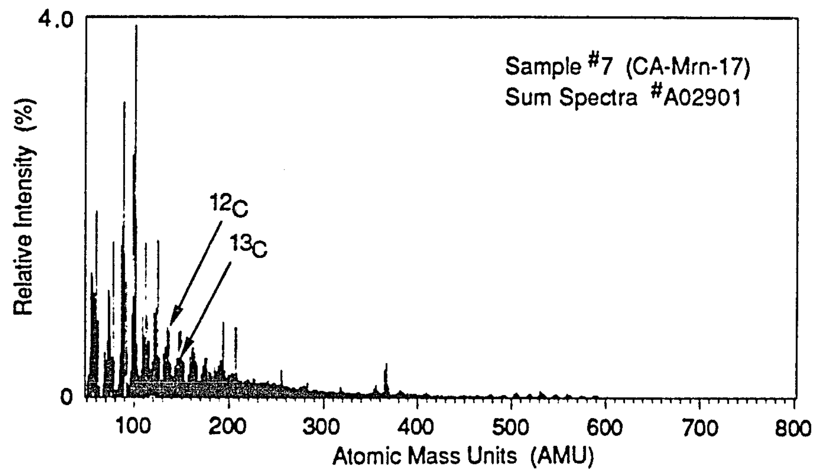


Figure 51. FIMS analysis (#A26502) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-FRE-137) near Mono Hot Springs, CA.

<u>Sample #7.</u> This bifacial tool (#A02901) was surface collected from a backwater slough adjacent to archaeological site CA-MRN-17 near Sausalito, California (Parsons 1986a). The chert artifact exhibited no banding, had a dull luster, was opaque, dark brown (Munsell 7.5YR, 2/0), and contained tan (Munsell 7.5YR, 5/2) inclusions. Analyses of the chert tool revealed the following traits (Table 4):

- SEM revealed a porous microcrystalline groundmass that appeared fused, similar to the Canyon City source material.
- EDX disclosed an elemental content of silica (60%), aluminum (18%), potassium (7%), sodium (7%), chloride (5%), calcium (3%), and a trace amount of iron (<1%). If saltwater contamination was discounted, these results would again be similar to the Canyon City source; however,
- The FIMS analysis produced a unique histogram pattern (Figure 52) that was reasonably similar to the Canyon City source (Figure 33).

No petroleum biomarkers were present at 500 amu, unlike most MB Cherts. Based upon the physical and analytical results, this specimen is Monterey Group Chert and was quarried from the Claremont Formation within the Berkeley Hills, near Canyon City, California. Although the findings were not identical with the Canyon City source, the divergent patterns could have been the result of chert not being homogeneous. More likely, this sample originated from an untested lithic source within the Claremont Formation, in the Berkeley Hills.



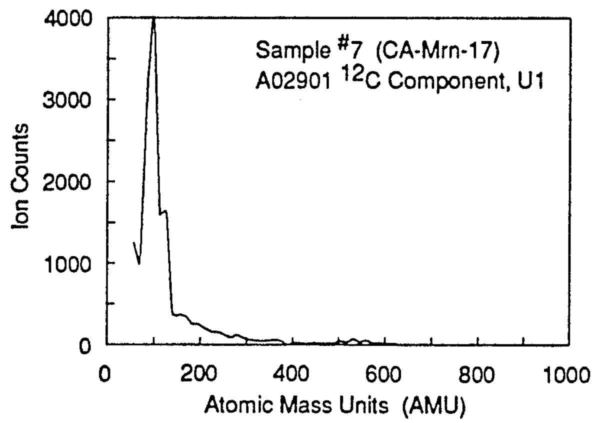


Figure 52. FIMS analysis (#A02901) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-MRN-17) near Sausalito, CA.

Sample #8. This chert core (#A26505) was recovered from an archaeological site (CA-ALA-343) in Fremont, California. The specimen was surface collected in 1986 during a salvage excavation from a construction zone, under the direction of Jeff Hall, a graduate student at San Jose State University. The chert was good quality, thermally altered, was dark brown (Munsell 10YR, 2/1), well-banded (first order) with white (Munsell 10YR, 8/2) bands, had a high luster, and was semitranslucent. It also contained fragmented gray (Munsell 10YR, 7/1) bands, tan (Munsell 10YR, 6/3) and gray (Munsell 10YR, 7/3) areas, white (Munsell 10YR, 8/2) inclusions, and pockets of porous white (Munsell 10YR, 8/1) diatomaceous material. Analyses of the chert artifact revealed the following traits typical of MB Chert (Table 4):

- SEM revealed a porous cryptocrystalline groundmass with a few vugs and pockets of free colloids;
- EDX disclosed pure silica content; and
- FIMS produced a histogram pattern (Figure 53) that was similar to Año Nuevo source material (Figure 27).

Because the Año Nuevo geologic source exhibited a similar histogram patterns to two other sources, additional data reduction was necessary for proper identification. Through three-dimensional analysis of the FIMS data, a proper identification was made. This additional data reduction traced the MB Chert artifact back to the Hunter Liggett lithic source, H3 (Figure 36).

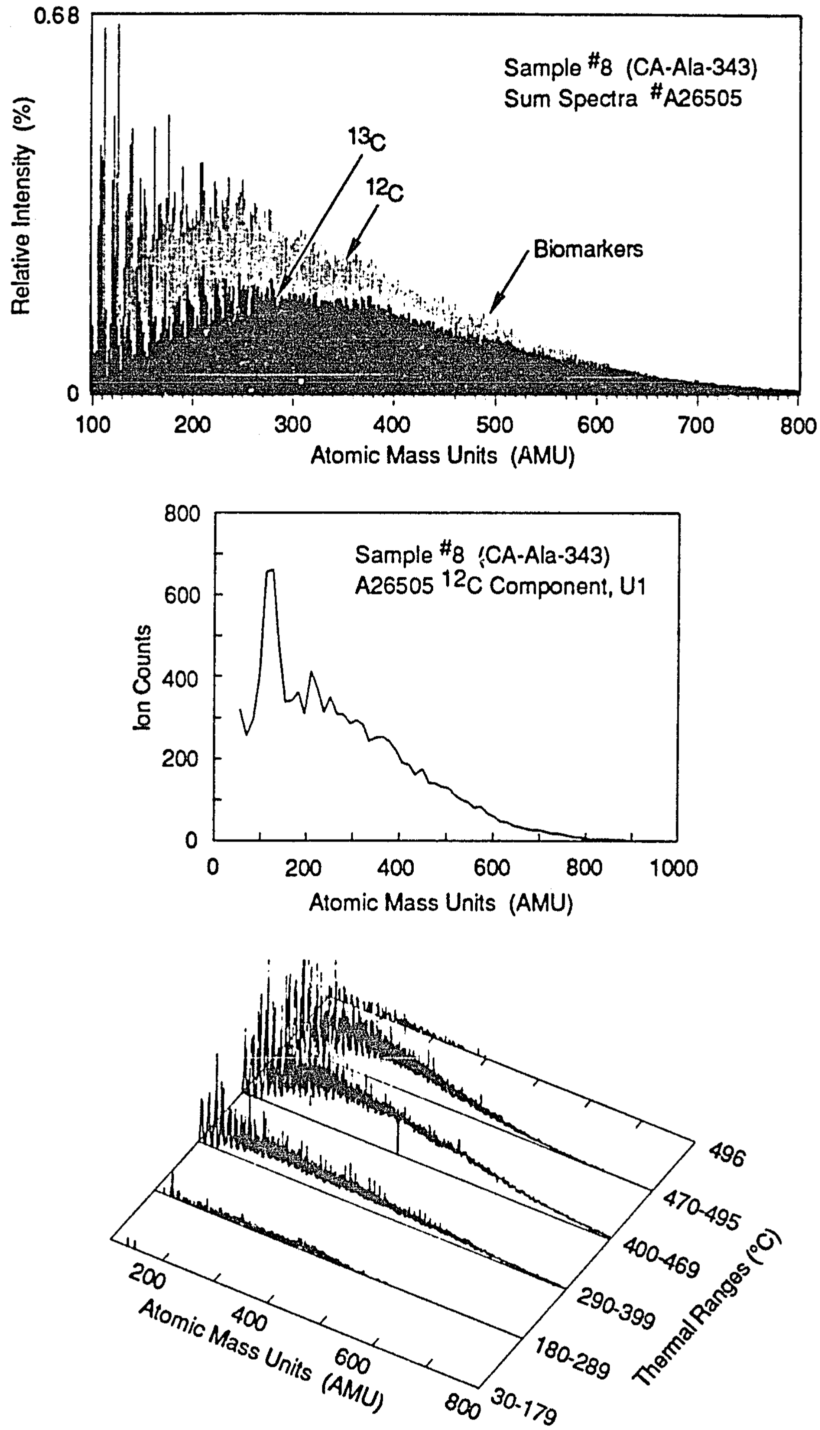
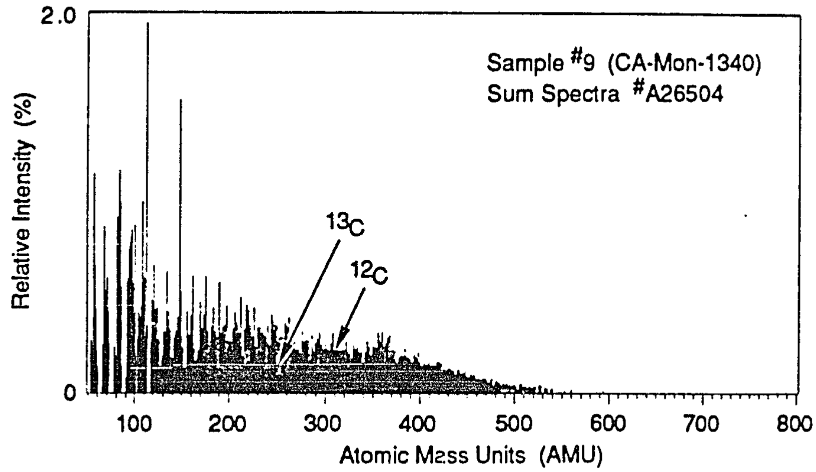


Figure 53. FIMS analysis (#A26505) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-ALA-343) near Fremont, CA.

Sample #9. The bifacial chert artifact (#A26504) was surface collected from a large archaeological site and quarry, CA-MNT-1340 (Parsons 1988). The MB Chert specimen had been thermally altered and exhibited a fracture caused by impact. The chert was dark-brown (Munsell 10YR, 2/1), faintly banded (first order), contained light-gray (Munsell 10YR, 8/1) inclusions, and exhibited a faint patina (Munsell 10YR, 4/1). Analyses of this chert artifact revealed the following traits, typical of MB Chert (Table 4):

- SEM revealed a cryptocrystalline groundmass with a few pockets of free colloidal material;
- EDX disclosed pure silica; and
- FIMS analysis produced a unique histogram pattern (Figure 54) that did not match any of the Monterey County sources identified in the Hunter Liggett area.

The archaeological site, where this sample was surface collected, appeared to have been a major lithic reduction center along Mission Creek, on Fort Hunter Liggett. No petroleum biomarkers were present in the specimen at 500 amu, unlike most MB Cherts. The absence of petroleum biomarkers and visible pot-lids are the result of thermal alteration (Parsons 1987). Analysis of the sample confirmed that it was MB Chert, but produced a fingerprint that was not similar to any other Hunter Liggett source (H1, H2, and H3) tested. Because of the large volume of MB Chert immediately available, this artifact most likely originated from a lithic source nearby (undocumented) and not out of the area.



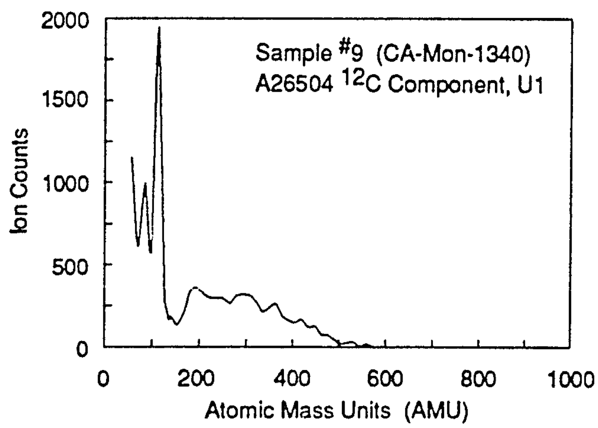


Figure 54. FIMS analysis (#A26504) of aromatic hydrocarbons contained within a Monterey Banded Chert artifact, recovered from an archaeological site (CA-MNT-1340) near Hunter Liggett, CA.

Summary of Artifactual Materials

At the recommendation of Dr. Gerow (Stanford University), this study only sought to fingerprint and source enough artifactual materials to demonstrate that the process was reliable and could be used with some degree of accuracy. The FIMS technique of sourcing artifacts manufactured from MB Chert has established itself in several ways;

- Through positively matching the fingerprints of two MB Chert artifacts (CA-SMA-211 and CA-SMA-218) from Año Nuevo with four Año Nuevo lithic sources (A1, A2, A3, and A4), FIMS consistency and reliability were established;
- By sourcing two widely separated Monterey Group Chert artifacts (CA-MRN-17 and CA-SON-295) with the Canyon City Lithic source (C1) in the Berkeley Hills;
- By sourcing a MB Chert artifact from Albion (CA-MEN-1704) to the Bolinas Bay lithic source, instead of the Point Arena or Schooner Gulch lithic sources (as previously thought); and
- By unexpectedly sourcing a MB Chert artifact (CA-ALA-343) recovered in Fremont to the Hunter Liggett lithic source H3, about 100 miles to the southeast.

Table 4
Central California Artifacts Analyzed

No.	Site	Item	Color	SEM	Material	Geologic Source
01	ALA-343	core	black	crypto	MB Chert	Año Nuevo Point
02	**CAL-13**	**biface**	**black**	**crypto**	**S. Chal.**	
03	FRE-137	biface	black	crypto	MB Chert	Canyon City
04	**FRE-1333**	**flake**	**amber**	**crypto**	**MB Chal.**	
05	MEN-1704	core	black	crypto	MB Chert	Bolinas Point
06	MEN-1809	flake	black	crypto	MB Chert	NA
07	MEN-1809	flake	black	crypto	MB Chert	NA
08	**MNT-101**	**flake**	**black**	**micro**	**Bk Shale**	
09	**MNT-101**	**flake**	**black**	**micro**	**Bk Shale**	
10	MNT-391	flake	black	crypto	MB Chert	Unknown.
11	**MNT-610**	**flake**	**black**	**micro**	**BF Chert**	
12	**MNT-947**	**biface**	**amber**	**crypto**	**MB Chal.**	
13	**MNT-947**	**flake**	**black**	**micro**	**BF Chert**	
14	**MNT-1215**	**flack**	**black**	**micro**	**BF Chert**	
15	MNT-1340	biface	black	crypto	MB Chert	Unknown
16	MNT-1340	biface	black	crypto	MB Chert	Unknown
17	MRN-017	biface	black	micro	MG Chert	Canyon City
18	**SCL-178**	**flake**	**black**	**micro**	**BF Chert**	
19	**SCL-341**	**flake**	**black**	**micro**	**BF Chert**	
20	SCR-007	flake	black	crypto	MB Chert	Año Nuevo Point
21	**SCR-009**	**flake**	**brown**	**crypto**	**Br Jasper**	
22	SCR-042	flake	black	crypto	MB Chert	Año Nuevo Point
23	**SCR-132**	**flake**	**brown**	**crypto**	**Br Jasper**	
24	**SLO-877**	**flake**	**black**	**crypto**	**MB Chal.**	
25	**SLO-877**	**flake**	**black**	**crypto**	**MB Chal.**	
26	SMA-211	biface	black	crypto	MB Chert	Año Nuevo Point
27	SMA-218	biface	black	crypto	MB Chert	Año Nuevo Point
28	**SMA-222**	**biface**	**red**	**crypto**	**R. Jasper**	
29	**SMA-222**	**biface**	**red**	**crypto**	**R. Jasper**	
30	SON-295	biface	black	micro	MG Chert	Canyon City

Bold entries were only examined for comparison.
MB = Monterey Banded (all contain only pure silica, Si)
MG = Monterey Group (most contain various trace elements)
BF = Black Franciscan (all contain many trace elements)
Bk = Black, Br = Brown, R.= Red, S.= Sierran

CHAPTER VI: SUMMARY AND CONCLUSIONS

For the analysis of various hydrosilicates in this multidisciplinary research project, field ionization mass spectrographic (FIMS), scanning electron microscopy (SEM), and energy dispersive x-ray (EDX) analysis proved to be valuable tools. They were the key techniques used for the determination of absolute geologic identities (fingerprints) of lithic (hydrosilicates) materials known as Monterey Banded (MB) Chert. Earlier attempts at sourcing hydrosilicates using standard mass spectrographic techniques had proved only marginally successful and were abandoned. This project was able to establish unique hydrocarbon identities of most geologic sources of MB Chert within the Central California Coast Range (Figure 45). By further manipulation of the FIMS data, this technique was able to differentiate between similar patterns. If the cost of the FIMS process could be reduced to a more practical level, more archaeologists would be more likely to employ it. FIMS could potentially be among the most valuable analytical tools available to the archaeologist. It could be used as extensively as x-ray fluorescence, obsidian hydration, or radiocarbon dating for the study of early economic systems within Central California prehistory.

A total of 71 lithic samples from 33 different geologic sources of black hydrosilicates were analyzed (Table 5). However, only two major source areas and four minor sources of MB Chert were located during the field surveys. In addition, four minor sources of Monterey Group (MG) Chert were

also found and fingerprinted. All other materials proved to be a black salacious shale, black Franciscan Chert, or black chalcedony (Figure 55).

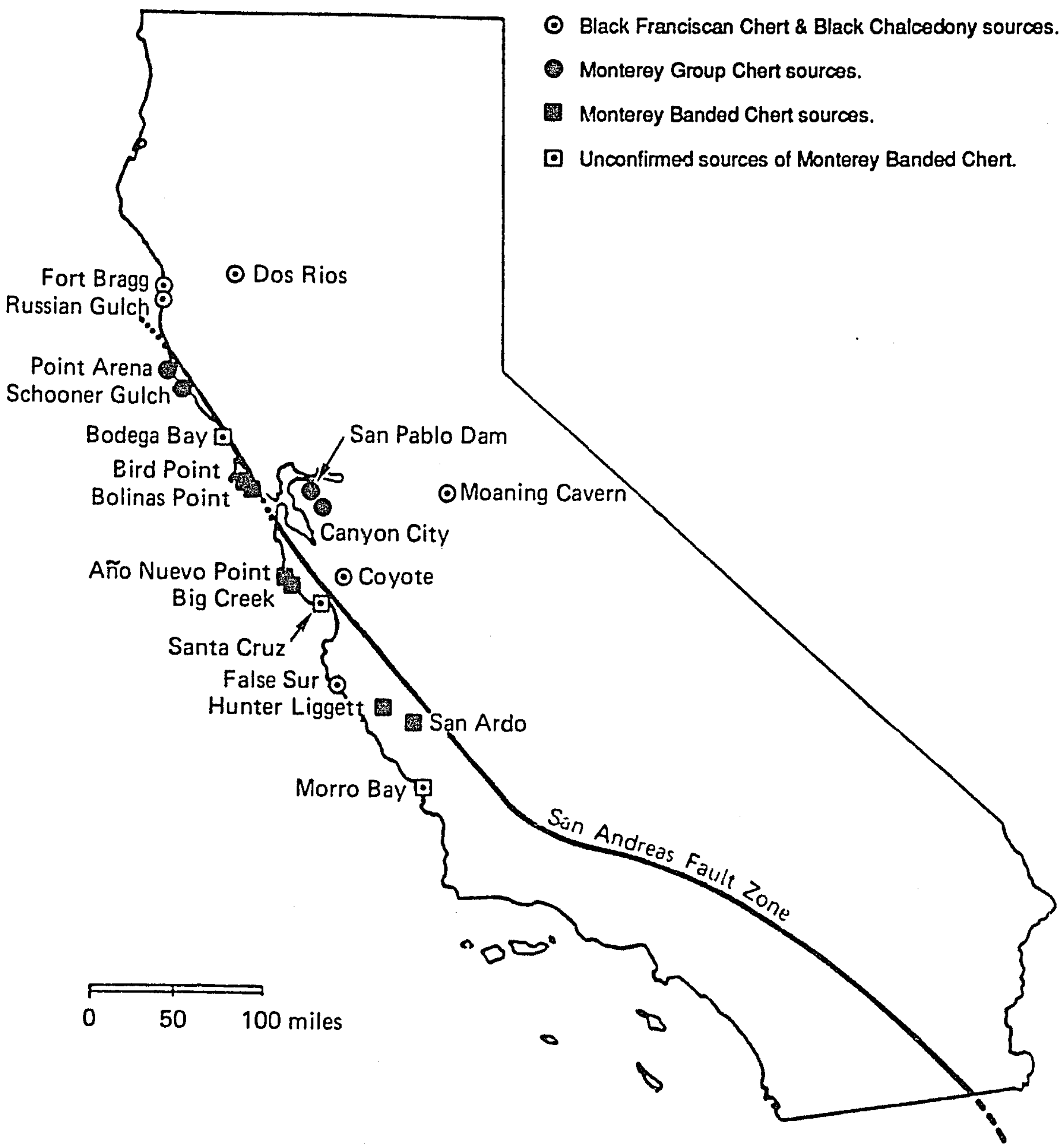


Figure 55. Monterey Banded Chert sources and associated lithics found within Central California's Coast Range.

Table 5
Sources of Black Hydrosilicates in Central California's Coast Range

A. **Major Source Areas of Monterey Banded Chert**

1. Año Nuevo Point (5)
2. Hunter Liggett
   a) Mission Creek (3)
   b) San Antonio River (8)
   c) Sulfur Springs (5)

B. **Minor Sources of Monterey Banded Chert**

1. Point Arena Cove (2)
2. Schooner Gulch (2)
3. Bolinas Point (2)
4. Big Creek (1)

C. **Sources of Monterey Group Chert**

1. Point Arena Cove (1)
2. Schooner Gulch (2)
3. San Pablo Dam (1)
4. Canyon City (2)

D. **Sources of Pseudo Lithic Materials**

1.	Año Nuevo	CR Jasper (1)
2.	Black Point	BF Chert (1)
3.	Bodega Head	BF Chert (1)
4.	Columbia	BS Chalcedony (2)
5.	Coyote	BF Chalcedony (1)
6.	Coyote Hills	RF Chert (2)
7.	Dos Rios	BF Chert (1)
8.	False Sur	BF Chert (1)
9.	Fort Bragg	BF Chert (4)
10.	Fort Ross	BF Chert (2)
11.	Golden Gate	RF Chert (2)
12.	Halls Valley	RF & GF Chert (2)
13.	Monterey	BS Shale (2)
14.	Muir Beach	BF Chert (1)
15.	Navarro Rvr.	BF Chert (3)
16.	Point Reyes	Bk Chert (2)
17.	Point Sur	BF Chert (1)
18.	Russian Gulch	BF Chert (1)
19.	San Ardo	?? Chalcedony (1)
20.	Sea Ranch	BF Chert (2)
21.	Tomales Bay	BF Chert (4)

Most amber varieties of these lithic materials were excluded from the survey. Also, six associated lithic materials were analyzed for relative comparisons. This study concluded that siliceous outcroppings of the Monterey Shale Formation were the sole sources of true MB Chert. In Central California, MB Chert only occurs west of the San Andreas Fault Zone.

After preliminary analysis of 30 artifacts from 24 archaeological sites, only nine specimens proved to be MB Chert, and only they received complete analyses. The fingerprinting process provided almost as many questions as it solved. For every chert artifact successfully sourced, there was another that originated from an undocumented source. The expanding data base generated by this study, has brought with it mixed blessings. As additional sources of MB Chert were located, documented, and fingerprinted, the ability to distinguish between them became more difficult. As stated earlier, hydrosilicates are not homogeneous, therefore, no two lithic samples will exhibit the same fingerprints, even if they came from the same cobble.

A previous study established that thermal alteration of MB Chert had little or no effect on the final FIMS analysis. The only tangible effect of heat-treatment was a relatively lower peak intensity and occasional destruction of the petroleum biomarkers (Parsons 1987). Experience with MB Chert sourcing and the analytical techniques used, will enable researchers to increase their levels of proficiency at lithic segregation (Jackson 1974).

For scientific research and statistical verification, it is important to have a relatively large sample size (Jackson 1974; Michels 1965). While the number of specimens analyzed in this report were comparatively small, this study represents an important beginning in the identifying sources of MB Chert and other hydrosilicates. There are literally millions of MB Chert specimens in public and private collections and even greater numbers unrecovered from archaeological sites throughout the state. One Año Nuevo site alone (CA-SMA-218), produced over 19,023 MB Chert specimens from a single 1 x 1 meter unit (Appendix B). To source even 10% of the MB Chert now in collections would require considerable expense in time and money. However, like obsidian studies, the process needs to begin somewhere and develop from that point.

Although MB Chert was a favored lithic material on the Central California Coast, the influence of geography and the obsidian trade appear to have had a striking effect on its distribution inland, according to the archaeological evidence. As with x-ray fluorescence of obsidian sources (Jackson 1974), detailed characterization of MB Chert sources can facilitate identification of distribution patterns and the location of undocumented sources. One good example of an undocumented source was characterized by fossiliferous MB Chert recovered from the Wilder Ranch site (CA-SCR-38). All (100%) of the MB Chert analyzed from this site was fossiliferous, while MB Chert from all other known sources produced less than 10% fossiliferous material. Therefore, an undiscovered lithic source of fossiliferous MB Chert must exist nearby.

The favorable results of this feasibility study have shown that FIMS is an extremely capable tool for fingerprinting and sourcing MB Chert. It is an excellent tool for differentiating between lithic sources. As with any research project, the more you learn, the more you realize what you do not know. A enormous amount of additional research still needs to be performed, the door is now open.

GLOSSARY

As a result of this research project being multidisciplinary in nature, and in an attempt to satisfy everyone concerned, there are numerous glossary entries. Three of the university departments being represented in this research project include Physical Science, Biological Science, and Social Science. All of the definitions cited in this glossary originated from standard industry references (Anonymous 1974; Dana & Dana 1952; Funk & Wagnall 1969; Hawley 1981; Hedberg 1976; Kirk-Othmer 1969/1982; Postek et al. 1980; Thomas 1976/1979; and Webster's 1985).

Aerobic Referring to an organism that lives, is active, or only occurs in the presence of free oxygen.

Agate A waxy silicate, consisting of variegated bands, clouds, or patterns of color. It commonly occupies vugs in volcanic and some other rocks.

Age A chronostratigraphic unit of geologic time that is of relatively minor rank and is synonymous with the term stage.

-quartz The use of and ß in the literature are used to describe the stable form of low and high temperature silicates (SiO_2), respectively.

Aliphatic One of the major groups of organic compounds that are characterized by straight, branched, or cross linked hydrocarbon chains. Subgroups are: paraffins (alkanes) which are saturated and comparatively unreactive; olefins (alkenes or alkadienes) which are unsaturated and quite reactive; and the acetylenes (alkynes) which contain triple bonds and are highly reactive.

Alkane Also called paraffin. A class of alphabetic hydrocarbons that are characterized by a straight or branched carbon chain (generic formula C_nH_{2n+2}). Their physical form varies with an increasing molecular weight, from a methane gas to waxy solid.

Alkyl A paraffinic hydrocarbon group which may be derived from an alkane by dropping one hydrogen from the formula.

Anaerobic An organism that lives, is active, or only occurs in the absence of free oxygen.

Andesite A volcanic rock composed of andesine and one or more mafic constituents.

Anoxic A condition of a solution with subnormal oxygenation.

Anticline A fold in the earth's surface that is convex upward with older rocks at the center.

Arkosic Any sedimentary rock or sandstone containing 25%, or more, feldspar.

Aromatic Relating to, or characterized by, the presence of at least one benzene ring. Also, used to describe cyclic hydrocarbons and their derivatives.

Atomic Mass Unit A unit of mass for expressing masses of atoms, molecules, or nuclear particles equal to one half of the atomic mass of the most abundant carbon isotope ($_6C^{12}$).

Basinal An enclosed or partly enclosed body of water. Also, a great depression in the surface of the earth's lithosphere that is occupied by an ocean.

Benthonic Relating to, or occurring at the bottom of a deep body of water, such as in the depths of the ocean.

ß-cristobalite The use of and ß in the literature is used to describe the stable form of low and high temperature silicates (SiO_2), respectively.

Biofacies An element of stratigraphy that deals with the remains or evidence of former life within a rock strata that exhibits a distinctive aspect, nature, or character.

Bioturbated An erratic flow of water, mud, or sand caused by living organisms.

Bitumen A naturally occurring asphalt or tar composed from various mixtures of hydrocarbons together with their derivatives.

Carbonaceous Referring to sedimentary rocks that are largely composed of carbon derived from organic material.

Carbonic Acid A weak dibase acid (H_2CO_3) derived from organic carbon or carbon dioxide (CO_2).

Catagenesis In accordance with something coming into being, or akin to its origin.

Chalcedony A cryptocrystalline form of sedimentary quartz.

Chron A corresponding geochronologic term for chronozone.

Chronozone A formal term for the lowest ranking division in the hierarchy of chronostratigraphic terms.

Clastic Referring to a secondary rock consisting of angular fragments of other primary rocks, normally volcanic.

Colloidal A gelatinous substance that consists of particles too small for proper resolution under an ordinary light transmission microscope.

Compound Composed of, or resulting from, the union of two or more separate elements, ingredients, or parts.

Concretion A nodular or irregular concentration of a material (calcites are most common) by the localized redeposited from a solution, generally about a central nucleus (shell or bone) and harder than the enclosing sedimentary material.

Conformity The relationship of adjacent geologic beds that are not separated by a sedimentary discontinuity.

Conglomerate Referring to a secondary rock consisting of well-rounded, water-worn pebble or cobble fragments of other primary rocks.

Couplets Two or more components forming a unit of a self-contained rhythmic episode.

Cretaceous The third and last period of the Mesozoic era, known as the Cretaceous period (76-140 million years BP).

Cristobalite A siliceous volcanic mineral (SiO_2).

Cryptocrystalline A mineral having a crystalline structure so fine that no distinct particles can be resolved under an ordinary light transmission microscope.

Cryptofractures A fracture so small that it cannot be detected under an ordinary light transmission microscope.

Cryptologic The scientific study of cryptography and cryptoanalysis.

Cyclization The formation of one or more rings within a chemical compound.

Debitage Relating to artifactual material that was discarded as refuse of an earlier time.

Decarboxylation To remove carboxyl from amino acids by enzymes.

Degradation The process of degrading to a lower rank or status.

Dendrite An irregular branching substance that resembles a shrub or tree.

Desiccator A container used to dry or dehydrate moisture from porous materials.

Detritus Residual materials produced by the disintegration or weathering of preexisting natural structures, both organic and inorganic.

Diabase An altered basaltic rock composed essentially of labradorite, pyroxene, or olivine and is characterized by an ophitic texture.

Diagenesis The recombination, rearrangement, or conversion of a rock's constituents by compacting or chemical reaction that produces a new product within sedimentary rocks.

Diatomaceous Consisting of the siliceous remains of microscopic, planktonic, unicellular organisms known as diatoms.

Dikes An intrusive tabular body of igneous rock that cuts across massive rock structures in a nearly vertical fashion.

Disproptionation The transformation of a substance into two or more dissimilar substances by simultaneous oxidation and reduction.

Eon A geochronologic unit that is greater than an era and refers to a major period of life.

Eonothem A chronostratographic equivalent of an eon.

Epoch A unit of geologic time, a subdivision of a period.

Era The largest formal geochronologic unit commonly used and consists of several adjacent systems.

Erathem An chronostratographic equivalent of an eon.

Exfoliation A successive separation of relatively thin shells during the mechanical weathering process of massive rock units.

Feldspar A group of abundant rock-forming minerals ($KAlSi_3O_8$).

Ferruginous Relating to, or containing, iron.

Foraminiferal Any of an order of large, chiefly marine, rhizopods that have calcareous shells.

Glassine A thin, strong, transparent, and flexible paper used in the laboratory as dust covers over specimens, to wrap samples, and to weigh materials.

Glauconitic A sedimentary rock of marine origin, containing a green mineral (hydrous potassium iron silicate) glauconite, that is closely related to mica.

Globigerina A deep water organism (<1200 ft) of the foraminiferal order of large, chiefly marine, rhizopods that have calcareous shells.

Graben A large block of the earth's crust, generally longer than it is wide, that has been downthrown along a fault zone relative to associated blocks on either side.

Graywacke A type of extremely fine-grained sandstone that is typically dark gray, low-grade metamorphic, tough, microbreccia of detrital siliceous rock fragments, and cemented with carbonates.

Greenstone An old field term relating to altered basic igneous rocks (basalt) that owe their color to the presence of chlorite, hornblende, and epidote.

Groundmass The material mass between phenocrysts (crystals), fossils, and other inclusions within igneous and other sedimentary rocks.

Horst A large block of the earth's crust, generally longer than it is wide, that has been upthrown along a fault zone relative to associated blocks on either side.

Hydrocarbon An organic compound containing only carbon and hydrogen and often occurring in petroleum, natural gas, coal, and bitumens.

Hydrolysis A chemical process of decomposition that involves the splitting of a chemical bond with the addition of the element water.

Hydrosilicate Any silicate rock or mineral that is created from an aqueous solution.

Intercolloidal The area between colloidal rock particles.

Interplanar The distance between planes of a mineral's molecular structure.

Ion An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electron. A free electron or other charged subatomic particle.

Ionization The process of converting wholly or partly into ions, to become ionized.

Island-Arc A chain of volcanic islands, generally located a few hundred kilometers from a trench where active subduction of one oceanic plate beneath another is occurring.

Juxtaposition The act of placing two or more things (formations, units, or features) side by side.

Kaolin A rock composed essentially of common clay minerals, mainly hydrous aluminum silicate, having the general formula $Al_2(Si_2O_5)(OH)_4$.

Kerogen A type of bituminous material, generally occurring in shale and yielding petroleum when heated.

Knap To shape stone, such as chert, by breaking with a quick blow from a hammerstone or antler mallet and then pressure flaking with a pointed bone tool.

Laminate To compress into a thin plate, to separate into laminae, or to unite layers of material by an adhesive or other means.

Lignite A brownish-black, coal-like substance that is in an intermediate stage between peat and bituminous coal. Also, where the texture of the original wood is still distinct.

Lipids Any of various substances that are soluble in nonpolar organic solvents. With proteins and carbohydrates, constitute the principal structural components of living cells. This includes fats, waxes, phosphatides, cerebrosides, and related or derived compounds.

Mafic A dark igneous material, dominantly composed of magnesium and having a high iron content.

Manometer An instrument for measuring the pressure of gases and vapors.

Maturation The process of becoming mature.

Mèlange A highly deformed mixture of rock material formed in areas of tectonic plate convergence or subduction.

Microcrystalline Any crystalline structure that is visible under an optical microscope.

Mineral A homogeneous, naturally occurring, inorganic, substance having a crystalline structure.

Monotonically Having the property of either never increasing or decreasing as the independent variable increases.

Olefin Also known as an alkene. A class of unsaturated alphabetic hydrocarbons having one or more double bonds, obtained by cracking naphtha or other petroleum fractions at high temperatures.

Oolite A spherical to ellipsoidal body.

Opaline Resembling opal in structure and appearance.

Orbicular In a spherical, ellipsoidal, or circular fashion.

Outgas To remove or lose occluded gases from a material by heating or placed under a vacuum.

Oxic A condition of a solution with normal oxygenation.

Pelecypod A division or class of the phylum Mollusca.

Phenols A caustic, poisonous, crystalline, and acidic compound (C_6H_5OH) that is present in coal tar and is regarded as a hydroxyl derivative of an aromatic hydrocarbon.

Phosphatic Relating to, or containing, phosphatic acid or phosphates (fertilizers).

Polycrystalline Consisting of more than one crystal, which is oriented in various directions.

Polycyclic Having more than one cyclic component. Also, having two or more fused rings within the molecule.

Polygenetic Having many distinct sources.

Porcelanite A term used to describe the physical appearance of silica rich rocks that exhibit a vitreous luster and color that are comparable to unglazed porcelain. A type of smooth, light-colored rock that has a smooth fracture surface, and is hard, chalky, opaque to translucent, china white, and resembles unglazed porcelain.

Pyridine A slightly yellowish to colorless liquid derived from the distillation of bone oil (C_5H_5N) or as a by-product of coking of coal ($N(CH)_4CH$). Also, it is the parent of many naturally occurring organic compounds, used as a solvent, a denaturant for alcohol, in the manufacture of pharmaceuticals, and as waterproofing agents.

Rhodonite A pale-red to vivid-pink triclinic mineral ($MnSiO_3$) that consists essentially of manganese silicate and is used as an ornamental stone.

Sard A deep orange-red variety of chalcedony that is classed by some as a variety of carnelian.

Serpentinite An ultrabasic rock consisting almost entirely of serpentine minerals, $Mg_3Si_2O_5(OH)_4$.

Silicate A compound whose crystal lattice contains the SiO_4 tetrahedra, either isolated or joined through one or more oxygen atoms to form groups, chains, sheets, or any other three-dimensional structure.

Silicoflagellates A class of unicellular organisms of alga or protozoan with a siliceous test.

Spectrometry The study of spectra that are the result, production, or relating to electromagnetic radiation and its associated phenomena.

Spicule A minute, hard, slender, siliceous, pointed, and spikelike particle. One of numerous minute siliceous bodies that support soft tissue within various invertebrates, such as sponges.

Sputter Coating The application of a thin layer (a few Å's thick) of gold palladium in a relatively low vacuum (10^{-3} torr) to specimens that are to be viewed under the scanning electron microscope. This is to drain off (discharge) the charge produced by the electron beam.

Stratotype A single continuously exposed section or facies that is favorable for time correlation. Unfortunately, complete stratotypes are uncommon.

Strike The compass direction of the line of interaction created by a dipping bed or fault and the horizontal surface. Strike is always perpendicular to the direction of the dip.

Subduction Zone The process of thrusting oceanic lithosphere back down into the earth's mantle along a convergent zone.

Syncline A linear downfold in sedimentary strata, the opposite of an anticline.

Torr A unit of pressure equal to $1/760^{th}$ of an atmosphere.

Turbidity Currents A downslope movement of relatively dense, sediment-laden water created when sand and mud on the continental shelf and slope are dislodged and are thrown into suspension.

Unconformity A surface of erosion or nondeposition that separates younger strata from older rocks.

Unsaturated Capable of absorbing or dissolving more of something.

Varves Any sedimentary rock, bed, or lamination that is deposited within 1 year's time. Also, a pair of contrasting laminae representing seasonal sedimentation, as in summer being light and winter being dark within a single year.

Vitreous Having the luster of broken glass, quartz, or calcite. Also, having no crystalline structure, amorphous.

Vug A cavity, often with a mineral lining of different composition from that of the surrounding rock.

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APPENDIX A

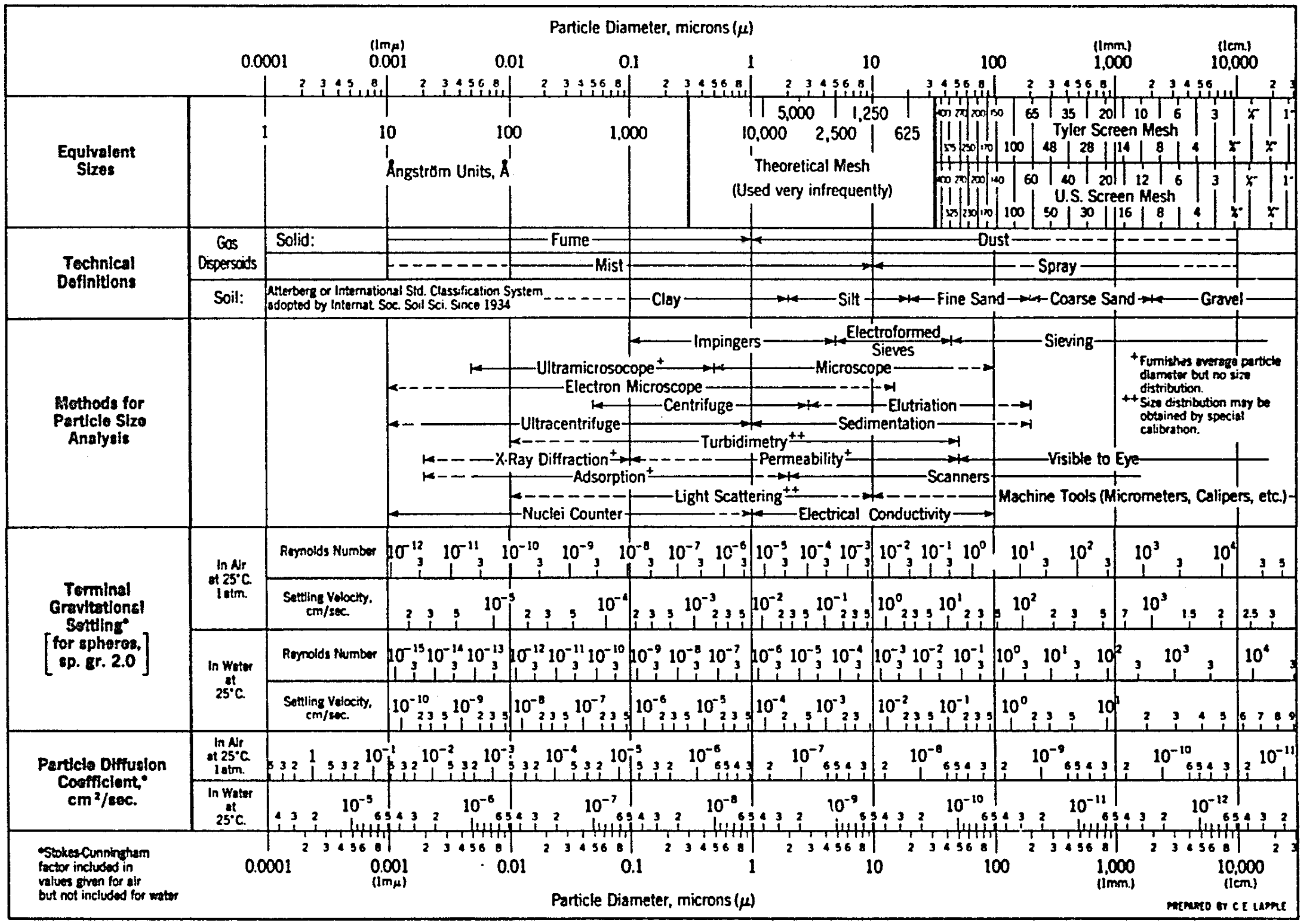
Characteristics of Particles

and

Particle Dispersoids

Table A1

CHARACTERISTICS OF PARTICLES AND PARTICLE DISPERSOIDS



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APPENDIX B

Archaeological Distribution of Monterey Banded Chert
and Other
Pseudo Materials Found Within Central California

Table B1
Archaeological Distribution of Monterey Banded Chert and Other Pseudo Materials Found Within Central California

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Alameda (ALA)	12		10					SFSU	Bickel, 1981
			11	3					Rackerby, 1967
	13	1685±85	2					SFSU	Bickel, 1981
			yes						Rackerby, 1967 CRD, 1990
	251		yes	3				SJSU	
	307	2700±300 3860±450	3		2			UCB	CRD, 1990
	309	2310±220 2530±105	61	yes			yes		Schenck, 1926 CRD, 1990
	328	2330±90	27					SFSU	CRD, 1990
		2339±150	yes					UCB	
			3				yes	HSU	
			7						Davis, 1959
			yes						Ringer, 1972
			11						Bickel, 1981
			yes						Parsons, 1980
	329	430±80	yes						Coberly, 1961
		1650±85	yes					UCB	CRD, 1990
			yes	2				SJSU	
			11	3		2		HSU	
			yes						Parsons, 1980
	342		84	12	7		16	SJSU	
	343	1300±0	3					SFSU	Cartier, 1988
			yes	yes	yes	yes			Parsons, 1986 CRD, 1990
	431				yes			HSU	
	459		yes					ACRS	Rogers, 1986
	479		yes					SJSU	
Alpine (ALP)									
Amador (AMA)									
Calaveras (CAL)	13	200±150 1200±150				yes			Parsons, 1986 CRD, 1990
	1243					yes			Parsons, 1986
Colusa (COL)									
Contra Costa (CCO)	27		yes					SFSU	
	126		2					UCB	
	137		3					UCB	
	138	150±0 1225±200	yes				yes	UCB	CRD, 1990
	151	1010±130 1260±110	yes	yes				UCB	CRD, 1990
	153		yes	yes				UCB	
	259	2180±250	3	2				UCB	CRD, 1990
	267		2				yes	UCB	
	272		yes					UCB	
	290		yes					UCB	
	295	2990±120 3680±0	yes	yes				UCB	CRD, 1990
	300		yes	yes			yes	UCB	

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Contra Costa (CCO)	312			yes			2	HSU	
El Dorado (ELD)									
Fresno (FRE)	48	2550±60	yes				yes	UCB	CRD, 1990
	80		yes					UCB	
	87		yes				yes	UCB	
	137		yes						Jackson, 1986
	144			3	7			SFSU	
Glen (GLE)									
Inyo (INY)									
Kings (KIN)	???		2					UCB	
Lake (LAK)	???			yes				UCB	
Madera (MAD)	107	285±90 1265±95			yes			SFSU	CRD, 1990
	117	245±100 2750±90		yes				SFSU	CRD, 1990
	118		2					SFSU	
	135						yes	UCB	
Marin (MRN)	3		yes					UCB	
	10			yes				UCB	
	17	2350±0	6	17	11		yes	SFSU	Pahl, 1986
		5575±220		yes				SFSU	Parsons, 1986 RCD, 1990
	26			yes				UCB	
	43		yes					SFSU	
	76			yes				UCB	
	78				yes			UCB	
	80			2	yes		2	UCB	
	115	720±130	yes					SFSU	CRD, 1990
	138	1910±90 2650±95	yes		100			SFSU	CRD, 1990
	168				yes			SFSU	
			yes	4	2		2	UCB	
	170	420±90 1350±95			10			SFSU	CRD, 1990
	192		yes					SFSU	
	216		48	15	yes			SFSU	
	232		7	4	2	yes	yes	UCB	
	235		yes					UCB	
	242		2	2				UCB	
	266		yes				yes	UCB	
	271		yes					UCB	
	278				yes			UCB	
	298		18	17	yrs			SFSU	
	375		23	yes	yes			SFSU	
	378		yes	yes				SFSU	
	383		10					SFSU	
	402		3		yes			SFSU	
	???		3					SFSU	
Mariposa (MRP)									
Mendocino (MEN)	112				yes			SFSU	
	133		yes					UCB	
	183		yes					UCB	
	187		yes					UCB	
	652		yes		yes			SFSU	
	764		yes					SFSU	

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Mendocino (MEN)	1704	330±60 4610±190	369					SJSU	Layton, 1990 CRD, 1990
	1809	410±80	777					SJSU	Layton, 1990
		690±70	2					SJSU	CRD, 1990
	1844	270±100 2310±100	259					SJSU	Layton, 1990 CRD, 1990
	1929		yes						Layton, 1986
	2023		yes						Layton, 1986
	2024		yes						Layton, 1986
	???		yes					SJSU	
Merced (MER)	5						yes	UCB	
	6		yes					UCB	
	49				2			UCB	
Mono (MNO)									
Monterey (MNT)	12	1895±95 2420±165	2					UCB	Howard, 1971 CRD, 1990
	14		yes					UCB	
	17	320±50 3900±80	yes					UCB	CRD, 1990
	18		yes					UCB	
	34		yes					UCB	
	57		6					UCB	
	71		yes					UCB	
	73		yes					UCB	
	85		yes					UCB	
	88	3190±100	2						Jones, 1984
		3610±105	yes					UCB	CRD, 1990
	89		2					UCB	
	100		5					UCB	
			yes						Parsons. 1985
			297						Hoover, 1988
	101	1020±60	74						Pritchard, 1984
		3870±90	21					ACRS	Dietz, 1987
			5					UCB	CRD, 1990
	103		10					ACRS	Dietz, 1981
	105		17					ACRS	Dietz, 1981
	107		356					ACRS	Dietz, 1981
			yes						Jones, 1984
	108	2940±70 4090±110	yes					UCB	CRD, 1990
	110		96					ACRS	Dietz, 1981
	111	1000±100	224					ACRS	Dietz, 1981 CRD, 1990
	112	340±100 4050±130	44					ACRS	Dietz, 1981 CRD, 1990
	113	260±100 660±100	210					ACRS	Dietz, 1981 CRD, 1990
	114	1890±110	103					ACRS	Dietz, 1981
		2250±120	yes						Jones, 1984 CRD, 1990
	115	1780±110 2140±110	80					ACRS	Dietz, 1981 CRD, 1990
	116	630±100 3650±130	568					ACRS	Dietz, 1981 CRD, 1990
			3					ACRS	Jones, 1984
	117	650±100 1040±110	42					ACRS	Dietz, 1981 CRD, 1990
	118	460±90 590±90	2					ACRS	Dietz, 1981 CRD, 1990

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Monterey (MNT)	119		12					ACRS	Dietz, 1981
	120		69					ACRS	Dietz, 1981
	121		yes					ACRS	Dietz, 1981
	126		9					ACRS	Dietz, 1981
	129	755±90 1220±70	2					ACRS	Dietz, 1981 CRD, 1990
	140		yes					UCB	
	145			yes				UCB	
	152	1040±80 11080±80	yes					UCB	CRD, 1990
	159		6					UCB	
	160		yes					UCB	
	183		yes					UCB	
	185	900±80 3160±100	2						Jones, 1984 CRD, 1990
	187		yes					UCB	
	227		yes					UCB	
	228	6880±135	7					UCB	CRD, 1990
	229	860±60	yes					UCSC	CRD, 1990
		7700±90	3002						Dietz, 1986
	233		20					UCB	
	234		yes					UCB	
	237		2					UCB	
	276		yes					UCB	
	281		51					UCB	
	282	1840±400		3					Jones, 1984
		1879±250	12					UCB	CRD, 1990
	283		yes					UCB	
	284		yes					UCB	
	285		5					UCB	
	298		43					ARS	Flynn, 1978
	300		2					UCB	
	365			2				UCB	
	370		95					UCSC	
	387	3200±130 4080±100	4						Jones, 1984 CRD, 1990
	390		4					ACRS	Dietz, 1981
	391	2210±80	yes					ARM	Cartier, 1984
		4910±100	yes					SJSU	Parsons, 1986 CRD, 1990
	414	5200±100 5540±160	211	yes	yes			UCSC	Patch, 1984 CRD, 1990
	415		24		yes			UCSC	
	479		yes					UCSC	
	480H		3						Jones, 1984
	486						yes	UCB	
	500		6		2		7	UCB	
	610						yes	SJSU	Parsons, 1986
	643		19				yes	UCSC	
	759H		yes					UCSC	
	792		yes						Parsons, 1985
	899		yes						Parsons, 1985
	1022		2					UCSC	
	1023		yes						Jones, 1984
			57		yes			UCSC	
	1215						yes	SJSU	Parsons, 1986
	1221		yes					UCSC	
	1223	770±80 1110±50	yes					UCSC	CRD, 1990

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Monterey (MNT)	1225		4					UCSC	
	1228		2					UCSC	
	1230		yes					UCSC	
	1232		2					UCSC	
	1235	780±70 1210±75	yes					UCSC	CRD, 1990
	1256	680±90 2410±80	yes					AC	Breschini, 1990 CRD, 1990
	1267		4					UCSC	
	1270H		yes		yes			UCSC	
	1277H		4					UCSC	
	1283		2					UCSC	
	1285		yes					UCSC	
	1340		yes						Parsons, 1986
			2					SJSU	
	???		yes					UCB	
	???		4					UCSC	
Napa (NAP)	161		2					SFSU	
Nevada (NEV)									
Placer (PLA)									
Sacramento (SAC)	6	620±200 2410±200	3		yes			UCB	Heizer, 1958 CRD, 1990
	21	250±150 980±150					yes	UCB	Schulz, 1981 CRD, 1990
	52						yes	UCB	
	107	2675±125 3075±105	2	3				UCB	Ragir, 1972 CRD, 1990
	151	510±150					yes	UCB	Schulz, 1981 CRD, 1990
	211		yes					UCB	
San Benito (SBN)									
San Francisco (SFR)	1		4					UCB	
	2		yes					UCB	
	21		yes					SFSU	
San Joaquine (SJO)	33		yes					UCB	
	56	2855±115					3	UCB	Ragir, 1972 CRD, 1990
	82						yes	UCB	
	91	1320±90 2985±160	yes					SSU	Johnson, 1986 Schulz, 1981 CRD, 1990
	142	1735±150 3445±110	yes					UCB	Schulz, 1981 CRD, 1990
	???		yes					UCB	
San Mateo (SMA)	17		yes						Hoover, 1925
			yes						Parsons, 1980
	18		yes						Hoover, 1925
			yes						Parsons, 1980
	19		yes						Hoover, 1925
			yes						Parsons, 1980
	20		yes						Hoover, 1925
			46						Roop, 1976
			yes						Parsons, 1980
			yes					UCB	

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
San Mateo (SMA)	22		yes						Phebus, 1973
	72	390±70 440±0	132						Clark, 1986 CRD, 1990
	77	390±70 3460±150	31					LSJU	Gerow, 1968 CRD, 1990
	80		yes						Parsons, 1982
	91		yes					UCB	
	97	1040±70	165					SJSU	Parsons, 1986
			3463					SJSU	Hylkema, 1985 CRD, 1990
	100	1060±95	yes	yes	yes			SFSU	Van Dyke, 1971 CRD, 1990
	101		3	2				SFSU	Moratto, 1971
	112		yes						Morris, 1979
			yes						Parsons, 1982
	113		yes						Morris, 1979
			yes						Parsons, 1982
	115	705±130	14					SJSU	Hylkema, 1985
			yes						Parsons, 1986 CRD, 1990
	116		yes						Parsons, 1982
	117		yes						Parsons, 1980
	118	380±45 635±70	416					SJSU	Hylkeme, 1985
			yes						Parsons, 1980 CRD, 1990
	126				6			SFSU	
	132		yes						Parsons, 1981
	140		18	yes				SFSU	
	147		12	yes					Salzman, 1984
	149		2					SFSU	
	151		yes					UCB	
	152		139					CDPR	Motz, 1985
			yes						Parsons, 1982
	155		yes						Wardell, 1975
	159		yes						Young, 1977
	182		968					SJSU	Parsons, 1986
	196		yes						Morris, 1979
			yes						Parsons, 1982
	197		yes						Morris, 1979
			yes						Parsons, 1982
	198		yes						Morris, 1979
			yes						Parsons, 1982
	199		yes						Morris, 1979
			yes						Parsons, 1982
	200		yes						Morris, 1979
			yes						Parsons, 1982
	201		yes						Morris, 1979
			yes						Parsons, 1982
	202		yes						Morris, 1979
			yes						Parsons, 1982
	204	615±170 1060±60	yes					LSJU	Bocek, 1986 CRD, 1990
	207H		yes						Clark, 1980
	211		yes						Hoover, 1925
			yes						Parsons, 1980
	212		yes						Hoover, 1925
			yes						Parsons, 1980
	213		yes						Parsons, 1980
	214		yes						Hoover, 1925

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
San Mateo (SMA)			yes						Parsons, 1980
	215		yes						Hoover, 1925
			yes						Parsons, 1980
	216		yes						Hoover, 1925
			yes						Parsons, 1980
	217		yes						Hoover, 1925
			yes						Parsons, 1980
	218	2880±60	yes						Hoover, 1925 CRD, 1990
			yes						Parsons, 1980
			19,023					SJSU	Hylkema, 1985
	219		yes						Hoover, 1925
			yes						Parsons, 1980
	220		yes						Parsons, 1980
	221		yes						Hoover, 1925
			yes						Parsons, 1980
			148					SJSU	Hylkema, 1985
	222		yes						Hoover, 1925
			yes						Parsons, 1980
			2552					SJSU	Hylkema, 1985
	223		yes						Parsons, 1980
	231		yes						Woodward,1981
			yes						Parsons, 1982
	236		yes						Hoover, 1925
			yes						Parsons, 1981
	237		yes						Hoover, 1925
			yes						Parsons, 1981
	238		yes						Hoover, 1925
			yes						Parsons, 1981
			409					SJSU	Hylkema, 1985
	239		yes						Parsons, 1982
	244		463					SJSU	Wheeler, 1983
			yes						Parsons, 1982
			1129					SJSU	Hylkema, 1985
	251		yes						Parsons, 1982
	271		yes						Hoover, 1925
			yes						Parsons, 1982
	272		yes						Hoover, 1925
			yes						Parsons, 1982
	ANI		20					Private	Collections
	ANP		295					Private	Collections
			2					CSM	Dickson, PC
			378					SJSU	Harris, PC
			741					SCM	S.C.A.Z.
			1550					CDPR	Latta, PC
			20					UCB	
			71					UCSC	
Santa Clara (SCL)	1	1200±200	yes					UCB	CRD, 1990
		3410±100	3					Private	Collection
			4					LSJU	
	3		15					SJSU	
	5		2					SJSU	
	6	250±60	yes					ARM	Cartier, 1981 CRD, 1990
	7	480±0 560±100	yes					ARM	Cartier, 1988 CRD, 1990
	45		yes	yes	yes			SJSU	

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Santa Clara (SCL)	51		yes					SJSU	
	52	630±100	7	14	yes	5		SJSU	Winter, 1977 CRD, 1990
	54	600±80	yes					SJSU	Hildebrandt, 1983 CRD, 1990
	55		6					SJSU	
	57				5			SFSU	
	58		yes					SJSU	
	64	1840±100	49	yes	3	4		ARM	Cartier, 1980
		6590±200	13	yes	3	4		SJSU	Winter, 1977 CRD, 1990
	65	5995±150 6450±160	37					SJSU	WVJC-2 CRD, 1990
	106	1380±110 5520±480	18					ARM	Cartier, 1980 CRD, 1990
	117			yes				SJSU	
	125		yes					SJSU	
	128	250±90 1700±110	213		121			SJSU	Winter, 1978 CRD, 1990
	135	1340±100	19	yes	yes			SJSU	CRD, 1990
	137	980±100 2670±90	4					SJSU	Winter, 1977 CRD, 1990
	163	300±0 2750±300	yes					SJSU	Hildebrandt, 1983 CRD, 1990
	172				2			SFSU	
	174		9					SFSU	
	178	770±240 9960±500	25					SJSU	Hildebrandt, 1983 CRD, 1990
	199		yes					ARM	Cartier, 1978
	203		3					SJSU	
	206		yes					SJSU	
	214		yes					SJSU	
	222		2					SCM	S.C.A.Z.
	223	380±300	yes		yes	yes	yes	SJSU	Winter, 1977 CRD, 1990
	224	1575±100	3		7	2	3	SJSU	Winter, 1977 CRD, 1990
	237		4					SJSU	Hildebrandt, 1983
	241		7					SJSU	Hildebrandt, 1983
	242		yes					SJSU	
	246	785±100			yes			SJSU	Winter, 1977 CRD, 1990
	268	280±90 1110±80	yes					ARM	Cartier, 1988 CRD, 1990
	276	670±100 1500±100	yes					ARM	Cartier, 1988 CRD, 1990
	292		yes					SJSU	
	300	1480±140 2460±130	2					ARM	Cartier, 1981 CRD, 1990
	302							ARM	Cartier, 1979
	314	1420±100	5				2	SJSU	CRD, 1990
	316	1200±130	2					ARM	Cartier, 1978 CRD, 1990
	341		3					ARM	Cartier, 1980
	343		3					SJSU	
	418		yes					SJSU	Hylkema, 1986
	450		yes					ARM	Cartier, 1983
	464	1030±60 1930±150	yes					LSJU	Bocek, 1986 CRD, 1990
	B. Ck		yes					SFSU	

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Santa Clara (SCL)	MtH		yes					Private	Collection
	SCU		yes					SJSU	
	SLAC		yes					SJSU	
	SM-I	5130±70	yes					LSJU	Gerow, pc
	SM-II	4350±125 4400±270	3					LSJU	Gerow, pc
	SM-III	2270±80	yes					LSJU	Gerow, pc
	???		741	10	4	2	yes	SJSU	WVJC-9
Santa Cruz (SCR)	1		19					UCB	
	2		11					UCB	
	3		yes					UCSC	Eastman, 1973
	4		yes					UCSC	Bicling, 1980
	5		7					UCB	
	7	3790±110	20					SFSU	CRD, 1990
		5390±100	64					UCSC	
			yes					SCM	S.C.A.Z.
			yes					CJC	
			13					UCB	
	7A		yes						Parsons, 1982
	7B		yes						Parsons, 1982
	7C		yes						Parsons, 1982
	7D		yes						Parsons, 1982
	7E		yes						Parsons, 1982
	9	1480±65	6					UCB	CRD, 1990
		2940±60	yes					SCM	S.C.A.Z.
	9		7,268					SJSU	Hylkema, 1985
			546					SJSU	Parsons, 1985
	10		yes					UCSC	
			yes						Parsons, 1982
	11		yes					SCM	S.C.A.Z.
	12		yes					SJSU	Jackson, 1986
			1015					SCM	S.C.A.Z.
			980					UCSC	
	13		yes					UCSC	
			yes					SCM	S.C.A.Z.
	15		yes						Vallier, 1977
			yes					SCM	S.C.A.Z.
	16		yes					SCM	S.C.A.Z.
	18		1613					UCSC	Gifford, 1978
			1651					UCSC	
	19		3					UCSC	
			yes						Parsons, 1982
	20	520±50	6300					SFSU	CRD, 1990
			6624					UCSC	Black, 1985
			yes						Parsons, 1982
			7	6			2	SCM	S.C.A.Z.
			632					CJC	
			4					SJSU	Parsons, 1986
			59					CJC	Roop, 1976
	21		yes					SCM	S.C.A.Z.
	23		yes						Dietz, 1979
	26		5					UCB	
	27		10					UCB	
			yes					SCM	S.C.A.Z.
			yes						Parsons, 1982
	28		yes						Parsons, 1982
	29		yes						Parsons, 1981

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Santa Cruz (SCR)	30		yes						Parsons, 1980
	31		27					SJSU	Parsons, 1986
			yes					SCM	S.C.A.Z.
	33	3580±260	517					ARM	Cartier, 1980 CRD, 1990
	35		9210					UCSC	Gifford, 1984
			1522					UCSC	
			yes						Parsons, 1982
	36		yes						Parsons, 1982
	37		12					UCB	
	38	1470±70 3480±120	912					CDPR	CRD, 1990
	40		yes						Kelly, 1976
			yes					SCM	S.C.A.Z.
	42		5					UCB	
			yes						Eastman, 1973
			216					UCSC	
	43		yes						Dietz, 1979
	44	2725±55	yes					SCM	S.C.A.Z. CRD, 1990
	46		yes						Parsons, 1981
	47		yes						Parsons, 1981
	48		yes						Parsons, 1981
	49		yes						Parsons, 1981
	50		yes						Parsons, 1981
	52		2					UCSC	
	53		yes						Parsons, 1980
	54		17					UCSC	
	55		yes						Magnusson,1971
	55		88					UCSC	
			yes						Parsons, 1982
	56		yes						Marsh, 1970
			86					UCSC	
			yes						Parsons, 1982
	57		yes					ARM	Cartier, 1971
			35					UCSC	
			yes						Parsons, 1982
	58		yes						Vallier, 1977
			7					UCSC	
			yes						Parsons, 1982
	62		yes					SCM	S.C.A.Z.
	68		yes					SCM	S.C.A.Z.
	72		yes					SCM	S.C.A.Z.
	79	2130±40 2345±100	yes					SCM	S.C.A.Z. CRD, 1990
	80		33					UCSC	
	82		yes						Parsons, 1982
	86	1630±110	yes					SCM	CRD, 1990
			yes						Parsons, 1986
	87		yes					SCM	S.C.A.Z.
	89		yes					SCM	S.C.A.Z.
	93	1760±70 3700±60	6					AC	Breschini, 1981
			96						Bourdeau, 1986
			yes					SCM	CRD, 1990
	94		7						Fox, 1980
			yes					UCSC	
			yes					SCM	S.C.A.Z.
			yes						Parsons, 1985

Table B1 (Continued)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Santa Cruz (SCR)	95		yes						Parsons, 1980
	96		yes						Parsons, 1981
	104		yes					SCM	S.C.A.Z.
	109		yes						Churchill, 1975
			yes					SCM	S.C.A.Z.
	111		yes					SCM	S.C.A.Z.
	112		yes					SCM	S.C.A.Z.
	114		yes					SCM	S.C.A.Z.
	116		yes					SCM	S.C.A.Z.
	117		yes						Roop, 1975
			yes						Parsons, 1981
	123		yes						Kelly, 1976
	132	1900±50	yes						Stafford, 1976
		5240±100	290					SJSU	Parsons, 1986
			3405					SJSU	Hylkema, 1986 CRD, 1990
	133		yes						Stafford, 1976
			yes						Parsons, 1980
	135		yes					SCM	S.C.A.Z.
	137		yes						Stafford, 1976
			yes						Parsons, 1981
	142		yes						Stafford, 1976
	143		yes						Fox, 1980
			yes						Stafford, 1976
	151		yes						Parsons, 1986
	158		yes						Bergthold, 1980
	160	490±70 760±90	yes						Farley, 1977 CRD, 1990
	163		25	yes	3		6	UCSC	
	168		1314					ARM	Cartier, 1978
	169		yes						Stafford, 1978
	170		yes						Stafford, 1978
	176		yes						???, 1978
	177	580±130 12520±740	625					ARM	Cartier, 1980 CRD, 1990
	178		yes						Sutton, 1978
			yes						Parsons, 1980
	188		yes						Dietz, 1978
			yes					SCM	S.C.A.Z.
	190		yes						Dietz, 1978
	195		yes						Parsons, 1980
	197		yes						Stafford, 1978
			yes						Parsons, 1981
	200		yes					SCM	S.C.A.Z.
	220		yes						Dietz, 1979
	227		yes					ARM	Cartier, 1980
			yes						Parsons, 1982
	251		yes						Parsons, 1982
	252		yes						Parsons, 1981
	253		235					SJSU	Parsons, 1986
	254		yes						Parsons, 1981
	269H		yes						Bourdeau, PC
	???		yes					UCSC	
	???		2					UCB	
Sierra (SIE)									
Solano (SOL)	276			yes			yes	HSU	
Sonoma (SON)	24				yes			SFSU	

Table B1 (Concluded)

County	Sites	Age BP	MBC	MGC	BFC	BC	UBC	Curated	Sources
Sonoma (SON)	299				4			UCB	
	???			2				UCB	
Stanislaus (STA)									
Sutter (SUT)									
Tulare (TUL)	???		2					UCB	
Tuolumne (TUO)									
Yolo (YOL)									
Yuba (YUB)									

AC = Archaeological Consultants
ACRS = Archaeological Consulting and Research Service
ARF = Archaeological Research Facility
ARM = Archaeological Resource Management
BC = Black Chalcedony
BFC = Black Franciscan Chert
CDPR = California Department of Parks and Recreation
CRD = California Radiocarbon Dates
CSM = College of San Mateo, JC.
H = Historic Site
HSU = California State University at Hayward
LSJU = Leland Stanford Junior University
MBC = Monterey Banded Chert
MGC = Monterey Group Chert
PC = Personal Communication
SCAS = Santa Cruz Archaeological Society
SCM = Santa Cruz Museum
HSU = California State University at Hayward
SFSU = California State University at San Francisco
SJSU = California State University at San Jose
SSU = California State Universiity at Sacramento
UBC = Unknown Black Chert
UCB = University of California at Berkely
UCSC = University of California at Santa Cruz